FHWA/NJ-80/002
80-002-7710

# CENTER BARRIER VISIBILITY STUDY

FINAL REPORT

BY

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PREPARED IN COOPERATION WITH THE U.S. DEPARTMENT
OF TRANSPORTATION, FEDERAL HIGHWAY ADMINISTRATION

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JANUARY 1978

NJ
TE
228
M87
1978
C.1

TECHNICAL REPORT STANDARD TITLE PAGE

| 1. Report No. | 2. Government Accession No. | 3. Recipient's Catalog No. |
|---|---|---|
| FHWA/NJ-80/002 | | |

| 4. Title and Subtitle | 5. Report Date |
|---|---|
| Center Barrier Visibility Study | January 1978 |
| | 6. Performing Organization Code: 80-002-7710 |

| 7. Author(s) | 8. Performing Organization Report No. |
|---|---|
| William Mullowney | |

| 9. Performing Organization Name and Address | 10. Work Unit No. |
|---|---|
| New Jersey Department of Transportation<br>Bureau of Operations Research<br>1035 Parkway Avenue<br>Trenton, NJ 08625 | 11. Contract or Grant No.: NJ HPR Study 7710 |
| | 13. Type of Report and Period Covered: Final Report<br>Sept. 1972 - Jan. 1978 |
| 12. Sponsoring Agency Name and Address<br>Federal Highway Administration<br>Washington, DC | 14. Sponsoring Agency Code |

15. Supplementary Notes

Conducted in cooperation with the U.S. Department of Transportation, Federal Highway Administration under the title "Center Barrier Visibility Study."

16. Abstract

A prototype delineation system was developed for installation on concrete median barriers. The visibility of the reflective devices was evaluated with respect to the following factors: the effect of weathering on the reflectivity of the reflectors, the effect of weathering and other destructive forces on the durability of the reflectors, and the effects of vertical placement, opposing headlight glare and wet night conditions on the visibility of an installation. Mounting materials and techniques were evaluated to determine the most durable with respect to weathering and other destructive forces. Eight millimeter color motion pictures were taken of an experimental installation under dry night and wet night conditions. An estimated cost for installing median barrier delineators was calculated separately for curves and tangents.

NJ
TE
228
M87
1978

| 17. Key Words | 18. Distribution Statement |
|---|---|
| Median Barrier Visibility, Delineation, Retro-reflectors, reflectivity, Wet-night conditions | C.1 |

| 19. Security Classif. (of this report) | 20. Security Classif. (of this page) | 21. No. of Pages | 22. Price |
|---|---|---|---|
| Unclassified | Unclassified | 70 | |

Form DOT F 1700.7 (8-69)

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TABLE OF CONTENTS


| | Page |
|---|---|
| List of Tables | iv |
| List of Figures | v |
| Summary and Conclusions | 1 |
| Recommendations | 4 |
| Introduction | 6 |
| Background | 6 |
| Study Design | 9 |
| Experimental Variables | 9 |
| Environmental Factors | 11 |
| Measures of Performance | 13 |
| Results | 15 |
| Effect of Wet Night Conditions on Reflectivity | 15 |
| Effect of Dirt and Windblown Debris on Reflectivity | 16 |
| Adequacy of the Retro-Reflectors as Median Barrier Delineators | 20 |
| Effect of Dirt Accumulation and Windblown Debris at the Vertical Positions | 20 |
| Effect of Opposing Headlight Glare at the Various Vertical Positions | 23 |
| Effect of Destructive Forces on Mounting Materials and Techniques | 25 |
| Cost Estimate for Installing Median Barrier Delineators | 28 |
| Discussion and Suggested Research | 28 |
| Retroreflective Terms | 32 |
| Appendix A - Detailed Test Procedures and Objectives | 34 |
| Appendix B - Detailed Product Description and Initial Material Testing Results | 47 |
| Appendix C - Questionnaire Instructions and Forms | 58 |

TABLE OF CONTENTS (CONT.)


| | Page |
|---|---|
| Appendix D - Cost Estimate Information | 65 |
| Appendix E - Correlation of Laboratory Photometric and Field Testing Results | 69 |
| List of References | 75 |
| Acknowledgements | 76 |

LIST OF TABLES


| | | Page |
|---|---|---|
| 1 | Retro-Reflector Comparison - Dynamic Visibility Studies | 18 |
| 2 | Percent of Original Specific Intensity Retained After Two Winters of Exposure | 19 |
| 3 | Comparison of Vertical Positions | 21 |
| 4 | Percent of Original Specific Intensity Retained After 30 Months Exposure | 23 |
| 5 | Durability of Mounting Materials and Techniques | 27 |
| 6 | Correlation of Laboratory Photometric and Static Visibility Rankings | 71 |
| 7 | Correlation of Laboratory Photometric and 3rd Dynamic Field Study Rankings | 72 |
| 8 | Correlation of New Photometric and Final Field Rankings | 74 |

## LIST OF FIGURES


| | | Page |
|---|---|---|
| 1 | Recommended Specification for Median Barrier Delineator | 5 |
| 2 | Median Barrier Delineators Used in the Major Evaluation | 10 |
| 3 | Mounting Devices | 12 |
| 4 | Most Reflective Selection Rating vs. Exposure Time | 17 |
| 5 | Retro-Reflective Device Comparison by Vertical Position | 22 |
| 6 | Set-up for Laboratory Visibility Study | 37 |
| 7 | Set-up for Static Visibility Test | 39 |
| 8 | Location of Reflectors at Route U.S.1, Trenton Northbound Side of the Median Barrier | 41 |
| 9 | Location of Reflectors at Route U.S.1, Trenton Southbound Side of the Median Barrier | 42 |
| 10 | Location of Reflectors at Route U.S.1, New Brunswick Northbound Side of the Median Barrier | 45 |
| 11 | Cross-sectional View of the Retro reflectors | 49 |

## SUMMARY AND CONCLUSIONS

This project was undertaken in order to develop a highly visible, durable delineator system for a Median Barrier installation. Products with potential application were solicited from numerous manufacturers and evaluated through progressive series of tests. Reflective materials were put through initial tests in order to determine relative reflectivity and visibility under limited environmental and operational conditions. From these tests, six devices were chosen for field evaluations. Potential mounting system devices, tested in the major evaluations, were chosen using a predetermined list of selection criteria.

The major evaluations were conducted with the various delineation systems under field conditions. The delineators were evaluated for the effects of dirt accumulation, deterioration of materials from weathering, headlight glare, dry and wet night conditions, and road and barrier geometry. In addition to this evaluation, color motion pictures were taken of an installation of the best devices in order to photographically document the effect of the above factors. The following conclusions were drawn from an analysis of the data gathered in the major evaluations:

1. When new, the Stimsonite 975 acrylic cube corner retroreflector was considered the most reflective selection.
2. As exposure to the environment increased the Swareflex 3290, convex glass lens retroreflector was rated the most reflective. However, some indication exists that the Stimsonite 975 reflector retained relatively superior reflectivity under wet night conditions.
3. Reflective tape using exposed glass beads in a pigmented binder was not rated as reflective as the delineators tested in the major evaluations.

This rating was performed only in the first dynamic study where comparisons between 30 feet sections of tape and 40 feet spacings of Stimsonite 975, Swareflex 3290 and Stimsonite 2400 delineators resulted in 22 out of 23 comparisons preferring the delineators over the tape.

4. At the top-side position (5" down from the top of the barrier), all reflectors except Reflexite were judged adequate and at the bottom-side location (14" from the top of the barrier), Stimsonite 975 and Swareflex 3290 were rated adequate. These judgements were made after 16 months (2 winters) exposure on the barrier.

5. The best vertical position of the delineator is on the top horizontal surface of the barrier. Although only one type of device (3M BD-21) was mounted on the top position, this position was inferred as being the best for all devices from the following results:

   a. After weathering, all devices tested in the major evaluations were rated more reflective in the top-side position than in the bottom-side position. All devices retained more of their original specific intensity, both when dirt covered and clean, in the top-side position.

   b. After weathering, the 3M BD-21 device, where mounted in all three positions, retained a substantially larger percentage of the original specific intensity in the top position than in the two side positions. Also, the top position was selected unanimously as the most reflective selection by a panel of observers being driven in a car at night.

The results also indicate that as the exposure time increases the difference in the weathering effects also increases. The top position will also save installation costs since reflectors for both directions can be put on one mounting bracket.

6. With heavy traffic volume in the opposing direction, headlight glare renders all barrier mounted delineators ineffective.

7. The visibility of the delineators was enhanced under wet night conditions. This is especially important since the visibility of the barrier and lane markings are diminished in inclement weather.

8. The Ethylene Vinyl Acetate mounting bracker is the most durable bracket tested. It has less potential for damaging vehicles than do rigid metal mounts and is not as vulnerable to damage from impacts.

9. The use of concrete studs to attach the EVA brackets to the barrier is superior to a butyl adhesive as far as longevity of the attachment and resistance to vandalism is concerned. However, rotation of the brackets around the single bolt was experienced, resulting in the inability to view the reflector, thus suggesting that a combination of bolt and adhesive would be better.

10. The cost of installing center barrier delineators was estimated using 1977 prices, at $0.08 per foot on tangents and $0.16 per foot on curves. This estimate used 80 ft. tangent, and 40 ft. curve spacings, and included all labor, overhead, materials and equipment needed for the installation. A bid price of $12/unit or $.15/$.30 per foot was accepted for a small job of 400 - 450 devices now in progress.

RECOMMENDATIONS

Based on these conclusions, the Division of Research and Development recommends the following specification for median barrier delineators for use in New Jersey (see Figure 1).

1. Reflector - Three inch diameter amber Stimsonite 975, or the equivalent.
2. Mounting Bracket - Black ethylene vinyl acetate. Dimensions as in Figure 1.
3. Attachment Methods - Butyl adhesive pad and primer and a concrete stud as described in Figure 1.
4. Vertical Placement - On the center of the top horizontal surface of the barrier.
5. Longitudinal Spacing - Eighty feet on tangents and 40 feet on curves.

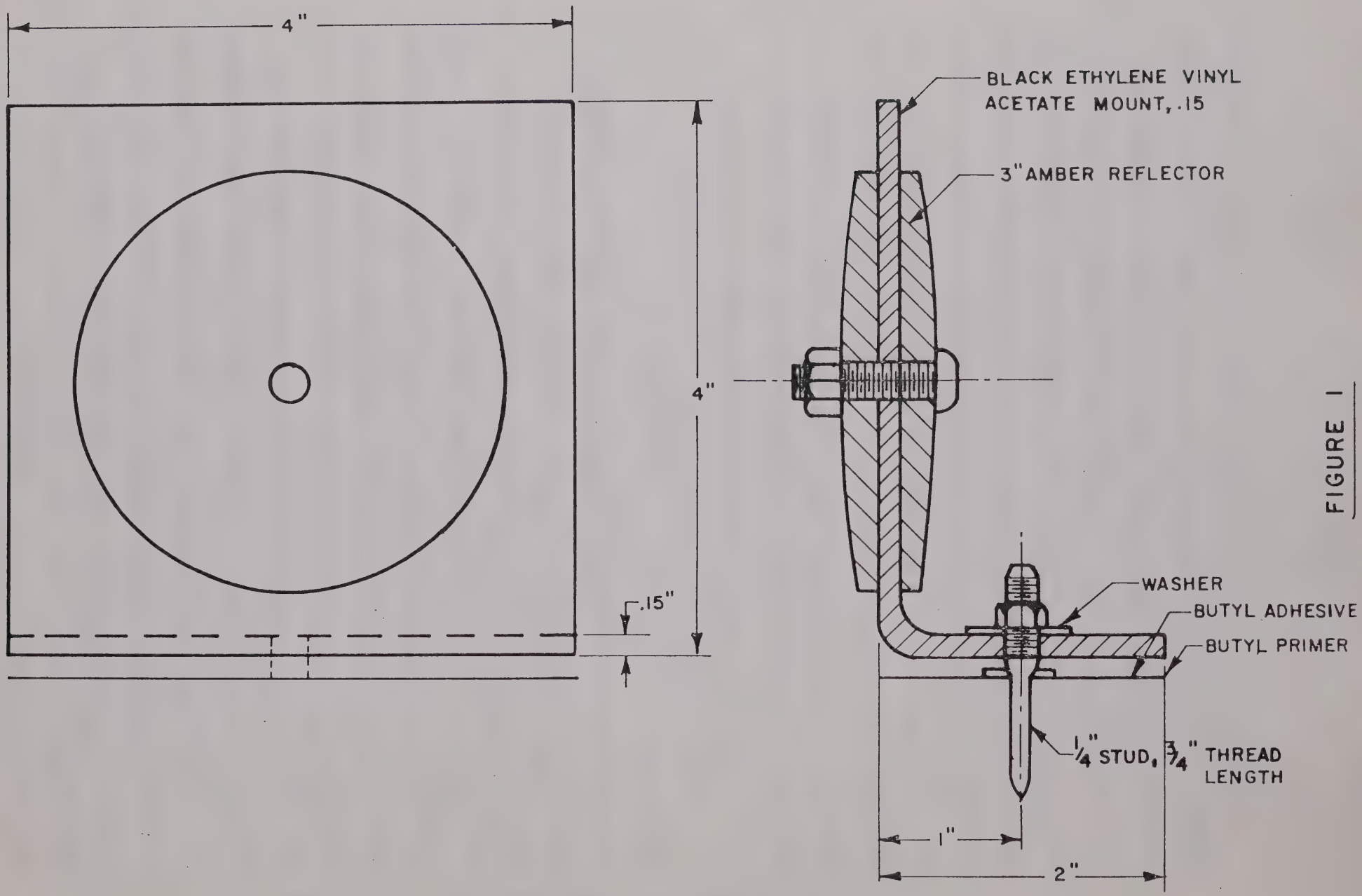



FIGURE 1

## MEDIAN BARRIER DELINEATOR

## INTRODUCTION

New Jersey type concrete median barriers, also known as center barriers, have proven to be an effective countermeasure for head-on collisions. Although the barrier offers reduced accident severity to motorists, it may create a visibility problem at night for some drivers. In 1975, 258 single car accidents which involved striking the center barrier occurred on 70 miles of U.S. Route 1 in New Jersey. One hundred thirty five of these accidents happened in the dark, while 52 occurred under wet-night conditions. The AADT on Route 1 ranges from 13,800 to 89,000. It is likely that a much larger number of single car strikings of the barrier go unreported, especially at night since no other vehicle is involved and since the purpose of the median barrier is to redirect a colliding vehicle back into its own lane of travel.

## BACKGROUND

Single car center barrier accidents result from what Alexander and Lunenfeld (1) describe as a "catastrophic system failure" of the "guidance level of driver performance." This performance level refers to the "drivers' task of selecting a safe speed and path on the highway." This selection involves, evaluating the immediate situation, making appropriate speed and path decisions, and translating these decisions into vehicle control actions. In order to perform these functions, the motorist needs to be provided with a sufficient number of unambiguous messages which are functional under a variety of weather conditions.

Delineation of median barriers will provide motorists with two guidance inputs in order to aid his safe passage along the road. Immediately in front of the vehicle, such delineation in a negative

sense will show where not to drive, that is, the median barrier will be perceived as a fixed, continuous, physical object to be aware of and avoided. In advance of the vehicle, the reflectors will provide positive delineation by outlining the path of the barrier.

The necessity for median barrier delineation is evident during nighttime driving conditions and especially during wet-night conditions. The visual contrast which exists between the barrier and the roadway that supplies near and advance guidance information during daylight conditions is reduced during dry-night conditions and vanishes almost altogether in wet-night situations. The use of white cement in barrier construction has increased the contrast between the barrier and the road surface at night but is ineffective on wet nights. Delineators are needed to give the barrier a line of discrete visual cues which would replace or supplement the greatly diminished wet-night guidance information.

Narrow medians containing center barriers are a natural dirt accumulation trap. Wind can blow dirt and sand across the roadway and trap it against the barrier, but when wind blows in the opposite direction, the barrier conceivably forms its own buffer and inhibits the debris from being blown away. A car's slipstream wind or natural wind which blows parallel to the barrier can drive the dirt and sand against the face of any reflectors mounted there. The accumulation of dirt and wear from wind blown sand can reduce the reflectivity of the delineators. Such a reduction in the reflectivity has been found by VanLear (2) to be as high as 90 percent of the original specific intensity. Rain and water splash seem to be the only natural cleaning agents.

The standard New Jersey type 32 inch high concrete barrier does not provide adequate protection from the glare of opposing headlights. The use of glare screens on top of the barrier may be an effective solution for this problem, but it has not yet become a practice in New Jersey. Different combinations of vertical placements and longitudinal spacings may tend to reduce the "washing out" effect of headlight glare on delineators, but this consideration must be linked with the effects of dirt, sand, and damage.

Road geometry can influence the visibility of a center barrier delineator installation. Crests, dips and left-hand curves in the road may result in the inability to view the delineators. For right-hand curves, the delineators may be lost to view because of preceeding traffic moving in the same direction, or they may have their reflectivity reduced due to the higher incidence angle. An investigation of curves with median barriers in New Jersey found that the highest incidence angle at which reflectors would be viewed was 35° thereby reducing the need for retroreflectors with wider angle characteristics.

Many years ago, the New Jersey Department of Transportation had delineated the top of the original parabolic sided barrier with red reflectors on vertical steel plates. Inventories of the condition of these delineators after about 10 to 12 years of service indicated that 58 percent out of 336 were damaged, bent or missing. The delineators had been maintained for several years until too many of them were found to be damaged. Possible causes of the damage are vandalism, impacts from cars or other objects, wet snow from snowplows and failure or rusting of the plates and the bolts which held the plates to the barrier. Because of the damage found with these reflectors and mounts, the use of flexible or spring back mounts with a more secure and durable attachment

system was considered for the project.

## STUDY DESIGN

The purpose of this study was to develop or find and test a delineator system which performs adequately on the median barrier after years of weathering. The characteristics of the system which affected the adequacy were the visibility of the total system and the durability of the various parts.

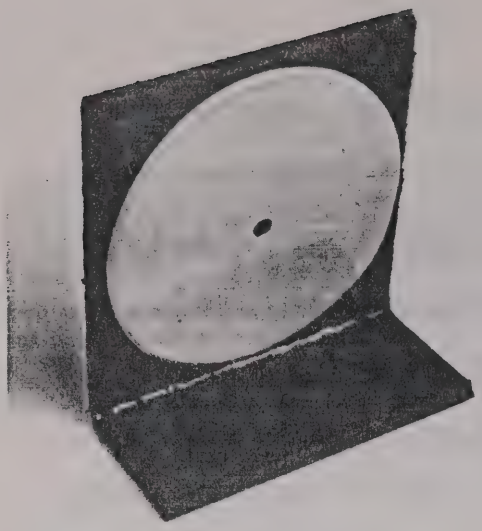
Experimental variables were chosen for study if they were thought to affect the visibility or durability of the system. In order to study these variables, environmental factors were identified which affected delineator performance. The relationship between the factors and the variables was observed through performance measures that were developed and used during the study.

### I. EXPERIMENTAL VARIABLES

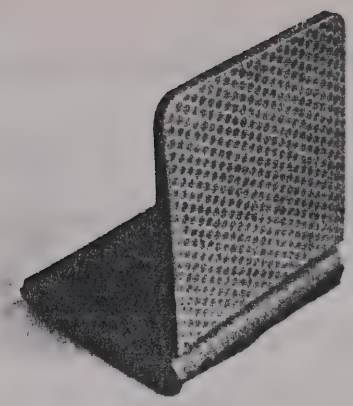
#### Types of Reflective Devices

Various types of reflective devices were obtained from an extensive survey. The list of materials was narrowed down to six amber devices used in the major evaluations by using the relative reflectivity of new devices and adaptability to barrier application as acceptance criteria. Details of the tests used and the reason for acceptance or rejection of the various materials submitted are in the Appendices A and B. Selected for the major tests were the following (see Figure 2):

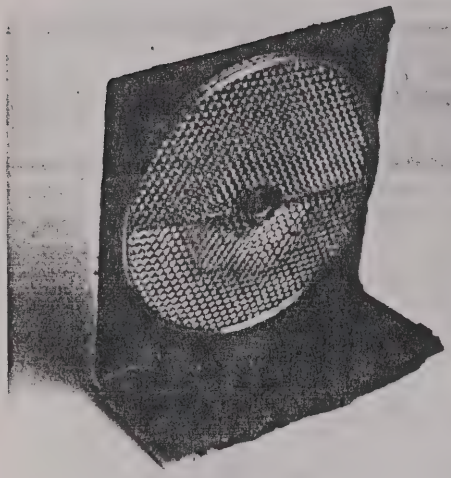
| # | Type of Device | Trade Name |
|---|---|---|
| 1 | Vinyl microscopic cube corner | Reflexite |
| 2 | Encapsulated lens sheeting | 3M BD-21 |
| 3 | Acrylic cube corner | Stimsonite 975 |
| 4 | Silvered convex glass lens | Swareflex 3290 |
| 5 | Wide angle, silvered acrylic cube corner | Stimsonite 2400 |
| 6 | Low profile acrylic cube corner | Stimsonite 960 |



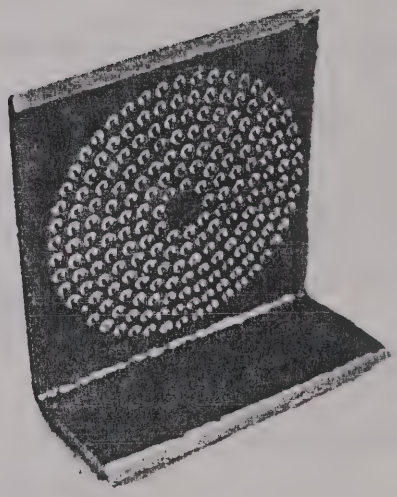
1 - REFLEXITE



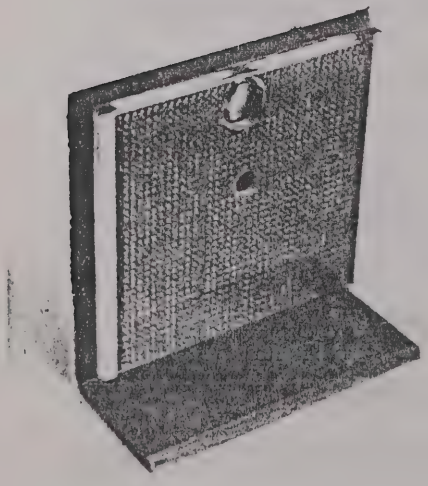
2 - 3M BD-21



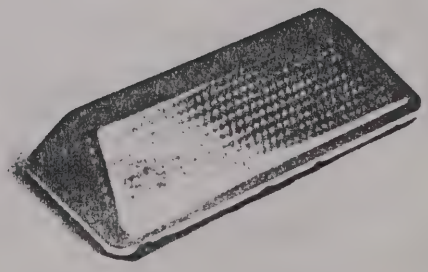
3 - STIMSONITE 975



4 - SWAREFLEX 3290



5 - STIMSONITE 2400



6 - STIMSONITE 960

FIGURE 2

MEDIAN BARRIER DELINEATORS

Vertical Position on the Barrier

Three vertical positions were investigated during the project: on top of the barrier, on the side of the barrier - 5" from the top and on the side - 14" from the top.

Originally, it was thought that headlight glare would render only the top mounted devices ineffective and, therefore, more initial emphasis was placed on the side mounted locations.

Mounting Materials and Techniques

Mounting brackets consisted of steel, EVA (Ethylene Vinyl Acetate) and scrap rubber (see Figure 3). The EVA and scrap rubber were expected to be superior due to their flexibility and reduced potential impact danger. Attachment materials studied included concrete studs and butyl adhesives.

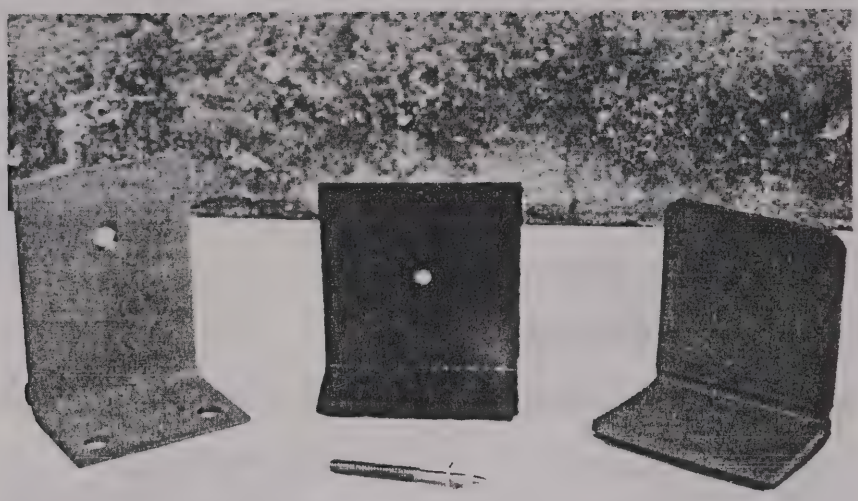
The mounting techniques utilized consisted of combinations of the various brackets and attachment materials. Only concrete studs were used on metal brackets, while either studs or butyl adhesive were used on EVA brackets, and only butyl adhesive was used on scrap rubber brackets.

## II. ENVIRONMENTAL FACTORS

Yu (3) reported four primary factors which affected median visibility: atmospheric conditions, headlight glare, topography and median design. This study concentrated on the first two factors listed above and selected three additional ones.

The five environmental factors which could affect the visibility and durability of the experimental variables were:

1. Weather conditions - the effect of rain on the reflectivity of the retro-reflectors was considered important since the prime function of the system is to provide adequate visibility in inclement weather.



| STEEL | ETHYLENE VINYL ACETATE | RUBBER |
|---|---|---|
| 3" x 4" x 2" | 3-1/2" x 3-1/2" x 1-1/2" | 3" x 3" x 2" |
| .10" thickness | .15" thickness | .20" thickness |
| .375" diameter holes | .375" diameter holes | |

CONCRETE STUD

Thread length 1-1/2"

Thread diameter 1/4"

Stud length 2-5/8"

FIGURE 3

MOUNTING DEVICES

2. Dirt accumulation - it was expected that a layer of dirt on the surface of the reflectors would seriously degrade their reflectivity. How the individual devices were affected by this and whether any gross differences were discernible at the various vertical positions was considered to be important.
3. Wear from windblown particles - for the same reasons as for dirt accumulation, the scratching and pitting effect of windblown debris was monitored.
4. Glare from opposing traffic - the effect of headlight glare on the visibility of the devices at the various vertical positions was studied.
5. Destructive forces - whether any of the various reflector types, mounting materials or techniques were destroyed, lost, or rendered unusable due to exposure on the barrier was studied. Possible damaging forces were: wet plowed snow, impacts from vehicles or flying objects, and vandalism.

## III. MEASURES OF PERFORMANCE

### Dynamic Visibility Studies

The six test reflectors were mounted on the barrier on U.S. Route 1 in Trenton in groups which enabled the relative brightness of the individual devices at the vertical positions to be determined. A questionnaire was developed and a team of observers chose the brighter reflectors from a vehicle travelling in the left lane of traffic. The speed was about 40 mph and low headlight beams were used. This team of observers consisted of engineers from the areas of Traffic Engineering, Maintenance, Quality Control, and Research. Groups of three or four of the raters were driven through the area and asked to fill out the questionnaire. The participating

engineer's normal job responsibilities were related to delineation, but they were not familiar with this particular experiment.

Ratings were made when the reflectors were new, after one winter's weathering, and after two winter's weathering (16 months' exposure on the barrier). The mounting configuration and the questionnaire were structured so the following information was obtained:

1. The brightness rating of each reflector type was compared against each of the others by mounting reflectors at each location in different paired combinations and side mounted heights. The choices made from all comparisons were totaled and a final rating and relative ranking were determined for each device.
2. The rater's direct preference of the various vertical positions was also obtained by driving past a long stretch of reflectors at the different heights and considering them as a whole.
3. The rater's opinions on the adequacy of the devices as median barrier delineators were obtained from observations of short stretches of each type of reflector.

Detailed procedures used in this test, diagrams of the reflector groupings and the questionnaire form and instructions can be found in the Appendix.

Photometric Measurements

Specific intensity values of the six test reflectors at the Trenton site were determined for three conditions: when the reflectors were new, after two winters' weathering when the reflectors were dirt covered, and after two winters' weathering when the reflectors had been cleaned. In addition, samples from each existing vertical position were removed and tested for the two latter conditions. All photometric tests were performed on an ESNA reflex photometer at incidence angles of 0° and 30° and divergence angles of .1°, .2°, and .5°.

Motion Picture and Visual Observations

After the first two dynamic studies were completed, the four highest rated reflectors (Stimsonite 960, 2400, 975 and Swareflex 3290) were selected for a major installation on Route 1 in New Brunswick. This installation was approximately one mile long.

Eight millimeter, color, motion pictures were taken of the installation in both dry night and wet night conditions. A Kodak XL360 camera with Ektachrome ASA160, Type G film was used. The driver and camera operator also made visual observations of the effect of glare and the number of reflectors which could be seen in advance of the vehicle. These observations were later compared to similar observations taken from the developed film in order to gauge how closely the motion pictures compared to the view of the road on the night the film was taken. The film was used to allow all the staff engineers to review the installation under both wet and dry conditions in the office.

Durability Survey for Mounts and Mounting Techniques

All analyses for durability were performed by visual observations. The various test locations were surveyed and the devices were inspected for the following types of damage: brackets were checked for the number missing, permanent deformation, rusting of the metal brackets and cracking of the plastic and rubber brackets; attachment devices were checked for looseness and rusting of bolts and studs, and rivets and buckling of the butyl adhesive pads; reflectors were checked for missing and broken devices.

## RESULTS

Effect of Wet-Night Conditions on Reflectivity

The reflectivity of the devices in the New Brunswick installation appeared to be enhanced during rain. This result was evident in both

motion picture analysis and visual observations made after one year's exposure. Two project engineers reported that approximately five devices could be seen in advance of the car during dry night conditions, while fifteen or more reflectors could be viewed during rain. Both observations were made while using the low headlight beams. The visibility of the devices in the rain was limited by glare and geometry but not by reduced reflectivity. Geometry limited device visibility by hiding side mounted delineators on left curves.

The increase in the number of devices visible in rain is thought to be caused by the following phenomena:

1. The rain may wash some of the dirt covering away from the surface thereby increasing reflectivity.
2. Decreased barrier and pavement marking visibility may cause the barrier delineators to contrast more with the background.

Effect of Dirt and Windblown Debris on Reflectivity

As the weathering or exposure time increased, the relative brightness of the convex glass lens reflector increased to the point that it was rated as the brightest after two winters of exposure. (Refer to Table 1 and Figure 4). This result was due to the dirt covering and scratching and pitting from windblown particles observed on the surface of the other reflectors. Documentation of this effect was also found in the photometeric measurements. The glass reflector had a considerably smaller percent reduction in specific intensity in all vertical positions when covered by dirt and when cleaned (see Table 2). The reduction in the photometric measurements after cleaning was due to the scratched and pitted reflector surface apparently from windblown particles.

MOST REFLECTIVE SELECTION RATING VS.
EXPOSURE TIME.

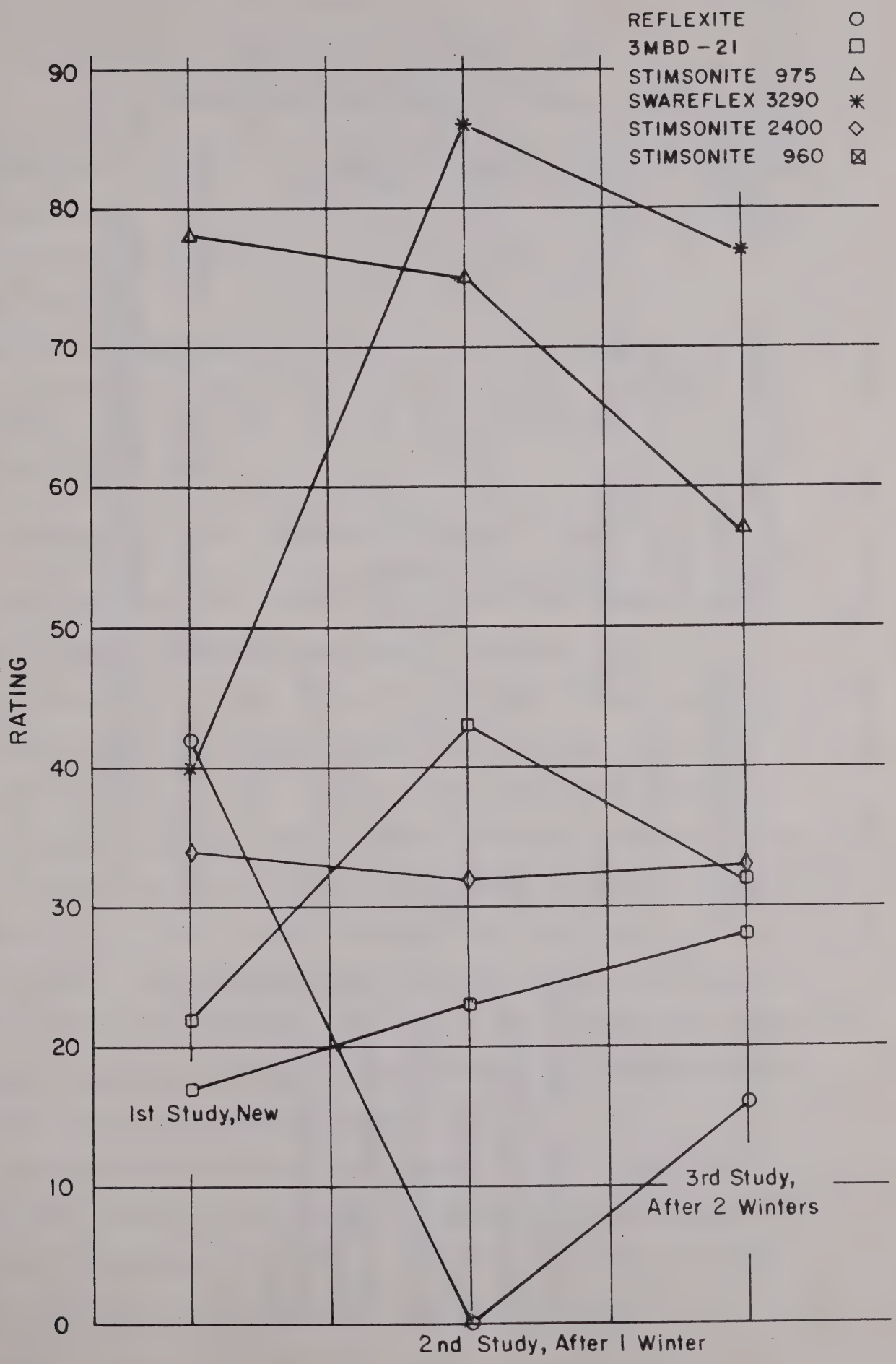


TABLE 1

RETRO-REFLECTOR COMPARISON - DYNAMIC VISIBILITY STUDIES

| | | 1st Dynamic Visibility Study - New Reflectors | | 2nd Dynamic Visibility Study - After One Winter's Weathering | | | | 3rd Dynamic Visibility Study - After Two Winter's Weathering | |
|---|---|---|---|---|---|---|---|---|---|
| | | Dry (13 raters) | | In Rain (4 raters) | | Dry (8 raters) | | Dry (13 raters) | |
| | | Rating | Rank | Rating | Rank | Rating | Rank | Rating | Rank |
| 1 | Vinyl Microscopic Cube Corner | 42 | 2 | 0 | 6 | 0 | 6 | 16 | 6 |
| 2 | Encapsulated Lens Sheeting | 17 | 6 | 6 | 5 | 23 | 5 | 28 | 5 |
| 3 | Acrylic Cube Corner | 78 | 1 | 95 | 1 | 75 | 2 | 57 | 2 |
| 4 | Silvered Convex Glass Lens | 40 | 3 | 37 | 3 | 86 | 1 | 77 | 1 |
| 5 | Wide Angle Silvered Acrylic Cube Corner | 34 | 4 | 28 | 4 | 32 | 4 | 33 | 3 |
| 6 | Low Profile Acrylic Cube Corner | 22 | 5 | 41 | 2 | 43 | 3 | 32 | 4 |

The ratings listed above were calculated in the following manner:

$$\text{Rating} = \frac{\text{number of times chosen as most reflective selection}}{\text{total number of comparisons with other reflectors}} \times 100$$

TABLE 2

PERCENT OF ORIGINAL SPECIFIC INTENSITY RETAINED
AFTER TWO WINTERS OF EXPOSURE (16 MONTHS)
0° INCIDENCE ANGLE, .5° DIVERGENCE ANGLE

| # | Reflector Type | Top Side | Top-Side Cleaned | Bottom Side | Bottom-Side Cleaned |
|---|---|---|---|---|---|
| 1 | Vinyl Cube Corner | 1 | 3 | 0 | 2 |
| 2 | Acrylic Encapsulated Lens | 8 | 16 | 3 | 3 |
| 3 | Acrylic Cube Corner | 5 | 11 | 1 | 2 |
| 4 | Silvered Convex Glass Lens | 33 | 68 | 15 | 29 |
| 5 | Wide Angle Silvered Acrylic Cube Corner | 6 | 13 | 3 | 7 |
| 6 | Low Profile Acrylic Cube Corner | 11 | 25 | 4 | 4 |

NOTE: The lower the percent reduction the greater the durability.

Some indication does exist that the acrylic cube corner device (#3) retains superior reflectivity during rain. The results from the second Dynamic Study in Table 1 show an acrylic cube corner with the highest rating when viewed in the rain while the convex glass lens device was rated highest under dry conditions. It is not known whether this phenomena existed in the third study since no ratings were taken under rain conditions.

An attempt was made to statistically correlate the initial photometric rankings of the six test devices with their final field rankings (Third Dynamic Study). The correlation coefficient was -0.275 and was not significant at the 95% confidence level. This is not surprising since photometric measures cannot predict the varying rates at which the different reflector surfaces are affected by the environment.

Significant correlation was found between the third dynamic study ranking and a ranking of the photometric analysis of the weathered devices. This result indicated that in order to determine the relative brightness of any group of reflective devices, a group of raters does not have to be

used as was done in this project. Rather, exposure of the devices for a period of time followed by photometric tests on the weathered devices would provide a simpler less costly way to rank retro-reflectors.

More detailed information on these findings can be found in Appendix E.

Adequacy of the Retro-Reflectors as Median Barrier Delineators

The raters viewed groups of the reflectors at three vertical positions and determined whether they performed adequately as median barrier delineators. A 50 percent threshold was chosen as a division between adequacy and inadequacy. The results indicated that after two winters' exposure, all devices with the exception of the vinyl cube corner were considered adequate at the top and top-side positions. At the bottom-side position, one acrylic cube corner (#3) and the convex glass lens reflector were judged adequate.

Effect of Dirt Accumulation and Windblown Particles at the Various Vertical Positions

The First Dynamic Study, rating unweathered reflectors, resulted in the bottom-side position being selected as the most reflective. This was true not only for the reflectors judged collectively (see Table 3), but also for each individual device (see Figure 5). After exposure to the environment occurred, the top-side position was selected as the most reflective overall and for each individual device.

Where devices were so mounted, the top position was chosen most reflective by all raters in the second and third studies (see Table 3). Also, as the exposure time increased, the trend of higher ratings with increased height of mounting became more pronounced.

TABLE 3

COMPARISON OF VERTICAL POSITIONS

PERCENT OF TIMES CHOSEN AS MOST[1] REFLECTIVE SELECTION

| | New | After One Winter | After Two Winters |
|---|---|---|---|
| Top-Side | 30 | 48 | 47 |
| Bottom-Side | 44 | 32 | 24 |

NOTE: "Equal" judgements were not counted

TIMES CHOSEN MORE REFLECTIVE SELECTION[2]

| | New | After One Winter | After Two Winters |
|---|---|---|---|
| Top | 0 | 10 | 13 |
| Top-Side | 2 | 0 | 0 |
| Bottom-Side | 8 | 0 | 0 |

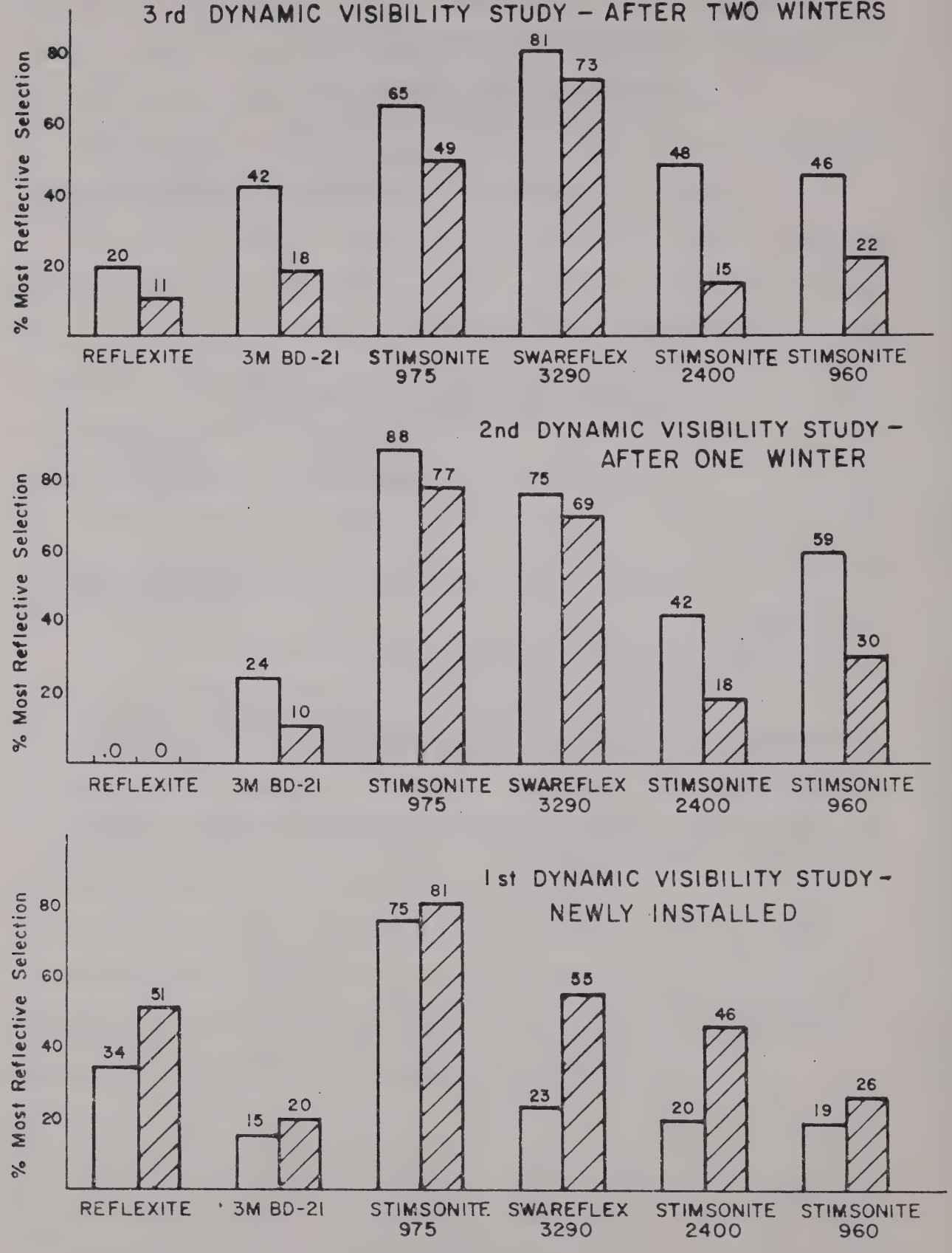
NOTE: "Equal" judgements were not counted.

[1]A composite of the results from seven separate locations comparing the six test devices. Devices were not mounted at the top position at these locations.

[2]A single question concerning one location where a device was mounted at all three vertical positions.

Figure 5

# Retro-Reflective Device Comparison by Vertical Position



These results can be attributed to the decreased amount of dirt covering and scratching and pitting experienced by the higher mounted devices. This effect is substantiated by the photometric data listed in Table 2 where the top-side position had a consistently smaller percent reduction in specific intensity both when covered with dirt and when cleaned.

The result obtained from the photometric evaluation of a location where the same device was mounted at all three vertical positions proved informative (see Table 4). While the top-side position showed slightly less reduction in reflectivity than the bottom-side, the top position was greatly less affected than the other two.

TABLE 4

PERCENT OF ORIGINAL SPECIFIC INTENSITY RETAINED AFTER 30 MONTHS EXPOSURE

| | DIRTY | CLEAN |
|---|---|---|
| Top | 31 | 47 |
| Top-Side | 3 | 6 |
| Bottom-Side | 2 | 3 |

It has been hypothesized that dirt and debris channeled down the side of the barrier by natural wind or a car's slipstream wind account for the much greater wear and dirt covering of the side mounted reflectors.

Effect of Opposing Headlight Glare at the Various Vertical Positions

In the study performed at the Trenton site, the raters were asked what effect headlight glare had on their ability to view the reflectors. In the first study, ten raters said the top or top side devices were more adversely affected by glare than the bottom side ones. One rater

noted an equal effect and two did not respond. In the second study, again ten said the top and top-side were affected more than the bottom, while two reported an equal effect.

The intensity of the effects noted by the raters varied from the top reflectors being completely "washed out" while the bottom mounted ones were less affected; to the top being partially affected while the bottom was not affected at all. Additional comments on glare included: "high beams wiped out both heights (top-side and bottom-side)," "all reflectors wiped out on curves" and "glare made eyes lower" or "completely blurred vision." This range of opinions on the effect of glare is not surprising since the opposing traffic volume was small and glare effects were intermittent.

At the New Brunswick site, three researchers viewed the reflectors at the peak evening hour in both dry and wet conditions. The effect of glare here was more dramatic. Headlights from platoons of cars travelling in the opposing direction "washed out" the visibility of long stretches of the reflectors. Although all reflectors were mounted at the top-side position and no evaluation could be made on the effect of the glare on the other positions, the extreme loss of reflector visibility appears to greatly reduce the effectiveness of barrier mounted reflectors under such conditions.

During visual observations of the effect of headlight glare it was noted that glare seemed more of a problem on a wet night than on a dry night. This phenomena was also apparent in observations of the film. Possible reasons for this apparent glare effect difference is the reflection of light off the wet pavement and the observers' wet car hood and the dispersion of light by the rain on the windshield. Reduced visibility due to rain on a car windshield has previously been noted by

Morris, et al (4).

Effect of Destructive Forces on Mounting Materials and Techniques

The most durable mounting technique found in the study was a butyl adhesive pad attached to a "low profile" marker. In 16 months of exposure at the northbound Trenton site and 12 months of exposure at the New Brunswick site, none of the reflectors were found to be missing (see Table 5). At the New Brunswick site, however, part of the butyl pad was lifting off the barrier under 16% of the reflector mounts.

After 16 months of exposure, two percent of the mounts utilizing a flexible bracket (Ethylene Vinly Acetate) attached to the barrier with a concrete stud were missing. Others did not remain taut against the barrier and the mounting bracket rotated around the stud, causing a loss of view of the reflective device. Stud installation was also a problem at times. The stud, at times hits a piece of aggregate and does not properly penetrate the barrier. The stud also may rotate while in the concrete, preventing the nut from being tightened.

Flexible mounts (EVA or scrap rubber) attached with a butyl adhesive had a higher loss rate than flexible mounts with concrete studs. At the northbound Trenton site, seven percent were missing with seven showing lifting of the butyl pad. In New Brunswick, 21 percent of the mounts were found missing, while 43 had lifting of the butyl pad. At the southbound Trenton site, 11 percent were lost in the 30 months of exposure. Lifting was not investigated here.

The metal mount attached with a concrete stud experienced the highest loss rate. At the northbound Trenton site, 53 percent were found missing, and seven of the remaining mounts were found bent after 16 months' exposure.

The reasons for the high loss of metal mounts are thought to be their inflexibility when impacted by some object or force, such as a vehicle, flying object, or wet snow from plowing operations. When hit, the metal

mounts apparently suffered deformation of the L-shaped bracket or failure of the concrete stud in the concrete or both. A possibility exists that metal mounts, having fallen off the barrier, would pose a danger to motorists if kicked up into the air by vehicle tires.

The flexible mounts do not pose the same danger to motorists as metal mounts, since they are plastic or scrap rubber and apparently remain longer on the barrier. The flexible mounts utilizing the concrete studs appear to be more durable than those using the butyl adhesive pad, but rotation of the bracket around the stud could be a problem. The reason for this occurrence may be loosening of the stud or nut when a hit, flexible bracket bends and puts a stress on the attachment mechanism.

Improper installation technique and the stress put on a butyl adhesive pad during an impact and the actions of vandals are thought to be responsible for failures with the butyl adhesive pad method. During installation, the primer must be dry before the mount is attached to the barrier. If the primer is not dry or if insufficient force is applied to the base of the bracket during mounting, premature failure may result. Mounting the L-shaped bracket towards or away from the oncoming traffic may make a difference in the amount of buckling or lifting caused by impacts. Whether there are any contraction-expansion effects during freeze-thaw cycles causing any butyl pad lifting is not known.

Apparent vandalism was experienced in one area of the southbound Trenton test site. In an illuminated interchange area, the flexible mounts suffered a higher attrition rate than anywhere else. It has been reported to project personnel that pedestrian traffic does exist at this section of Route 1 even though access to the area is difficult. One reflector was found dangling from the barrier as if a vandal stopped before completing the act. Vandalism is suspected, since mounts using a butyl pad can be removed from the barrier by a slow, steady force,

TABLE 5

DURABILITY OF MOUNTING MATERIALS & TECHNIQUES

NORTHBOUND TRENTON SITE AFTER 16 MONTHS' EXPOSURE

| Type of Mount | No. of Mounts Installed | No. of Mounts Missing | % Missing | No. of Mounts Bent | No. of Mounts With Butyl Pad Lifting | No. of Damaged Reflectors |
|---|---|---|---|---|---|---|
| Metal with concrete stud | 45 | 24 | 53 | 7 | --- | 6 |
| EVA with concrete stud | 47 | 1 | 2 | 0 | --- | 0 |
| EVA with butyl adhesive | 2 | 1 | 50 | 0 | 0 | 0 |
| Butyl adhesive on rigid low profile marker | 20 | 0 | 0 | 0 | 0 | 0 |
| Scrap rubber mount with butyl adhesive | 12 | 0 | 0 | 0 | 7 | 0 |
| SOUTHBOUND TRENTON SITE AFTER 30 MONTHS' EXPOSURE | | | | | | |
| Scrap rubber mount with butyl adhesive | 148 | 17 | 11 | --- | --- | --- |
| NEW BRUNSWICK SITE AFTER 12 MONTHS' EXPOSURE | | | | | | |
| EVA with butyl adhesive | 75 | 16 | 21 | 0 | 43 | 0 |
| Butyl adhesive | 57 | 0 | 0 | 0 | 9 | 0 |

whereas the large, instantaneous force of a vehicle impact apparently temporarily flattens the flexible bracket but does not rip the pad off the barrier. This occurrence was noted in New Brunswick where an EVA-butyl adhesive mount remained on the barrier even though a force from an impacting vehicle ripped the reflector off and the rivet and washer through the mount. The hole through which the reflector was riveted to the bracket was enlarged and elongated but the butyl pad and mount were otherwise unaffected.

## COST ESTIMATE

The cost of installing median barrier delineators on curves and tangents on New Jersey highways was estimated using an arbitrary spacing of 80 feet on tangents and 40 feet on curves. The equipment and labor cost estimates were based on the use of New Jersey Department of Transportation equipment and employees at 1977 rates. The equipment costs included insurance, gas, oil, parts and labor for repairs and maintenance, and depreciation. This information was supplied by the Bureau of Equipment, while labor costs were obtained from the Bureau of Maintenance. The estimated cost per foot of barrier for installing delineators on tangent sections is $.08, while delineators on curved sections would cost $.16 per foot of barrier. The cost of the barrier per foot ranges from $25 to $38.

## DISCUSSION AND SUGGESTED RESEARCH

The enhancement of their reflectivity in wet night situations suggests the ability of the delineators to provide the motorist with more information on the barrier hazard. However, the effectiveness of the delineators is diminished when opposing headlight glare exists. As previously stated the erection of glare screens may be a solution to this problem. Research into the use of delineators on barriers topped by glare

screens would be necessary since the screen may act similarly to the barrier in channeling dirt into the face of the reflector. Moving the reflector to the top of the screen may cause a reduction in the visibility of the delineators since headlight intensity drops off rapidly with increased height. Cook (5) found that 4 foot high mountings resulted in shorter detection distances than 2.5 foot heights which is the approximate height of both car headlights and the center barrier.

The cost of maintaining a center barrier installation over a more extended period of time also needs investigation. Included in this study could be possible cleaning methods, determination of the effective life of delineators and mounts, and whether a delineator, of equal reflectivity after long weather exposure compared to convex glass lens device, could be manufactured in the United States at a lower cost thus saving on the original installation costs.

After two winters' exposure on the barrier (16 months), all retro-reflectors were considered adequate at the top position (with the exception of the vinyl device). Future studies might determine whether this trend would continue, that is, which retro-reflector types would remain adequate at the top position for how long. A continuance of this analysis might allow considerations other than brightness to be primarily used in choosing a retro-reflector. Such factors could be cost, resistance to impacts, and resistance to vandalism.

A study of the varying rates at which harder reflector surface materials are affected by the elements may be useful. The dynamic visibility study performed in this project indicates that vinyl surfaces are most quickly affected while glass surfaces least quickly. Acrylic surfaces fall in between. Whether this trend would continue as exposure time increased is not known. A hard coating process such as has been

applied to raised pavement markers may improve the resistance of the acrylic surfaced devices to abrasion. With such an improvement, acrylic devices may be found to be as durable as the glass ones.

Further research is also needed in developing a more durable mounting technique. This paper has recommended using a concrete stud and a butyl adhesive pad for mounting. Although this combination of attachment methods was not studied, it is recommended because of the following reasons:

1. The butyl would protect the barrier surface from spalling where the mount was attached. Two studs would not do this.
2. The butyl pad would protect the concrete stud from rusting.
3. The butyl pad would prevent rotation of the bracket around the stud.
4. The use of concrete stud would prevent the failure of the system if the butyl pad lifted off the barrier.
5. The use of the concrete stud would offer more resistance to vandals.

Documentation of these possible advantages in a field situation is necessary. Also whether a steel or aluminum rectangular plate covering the entire face of the bracket touching the barrier would be necessary to exert even pressure on the adhesive (thus preventing lifting around the edges) could be studied.

The longitudinal spacing used in this study was chosen at 80 foot spacing on tangents and 40 foot spacing on curves. Increased spacing would certainly lower installation and maintenance costs, but what effect this would have on overall effectiveness of an installation is not known. Shorter spacing would result in increased costs, but might help combat the effect of headlight glare. Shorter spacing may also be necessary in areas of extremely high dirt accumulation such as intersections. Research into these areas should prove helpful. It could be hypothesized

that extremely bright reflective devices could cause a glare problem in themselves if spaced too closely. However, no products evaluated in this study were found to cause such a problem at spacings which were used.

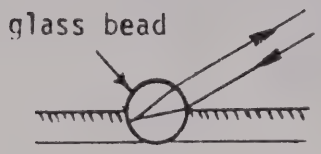
Investigation into whether a highly visible and durable center barrier installation has any beneficial effects on road safety is also important. Before and after accident analysis, and other traffic performance measurements such as lateral placements and lane volumes during wet nights might be used in this endeavor. The installation of center barrier delineators along with other devices meant to perform in inclement weather (snowplowable raised pavement markers) would should the beneficial effect of a total delineation system.

## RETROREFLECTIVE TERMS (6)

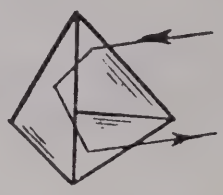
Retroreflective: That which reflects and returns light in a direction close to the direction from which it came. This characteristic can be maintained over a wide variation of the angle made by the incident light ray and the normal reference to the retroreflective surface.

Retroreflective element: A retroreflective optical unit, which by refraction and reflection produces the phenomenon of retroreflection.

Cat's Eye Device




Spherical Ball



Cube Corner Device

Retroreflective material: The substance of which the retroreflective elements are composed (glass, vinyl, acrylic).

Retroreflective sheeting: A retroreflective device preassembled as a thin film.

Retroreflective system: An assembly of retroreflective elements, all of which reflect light in the direction of its source.

Encapsulated retroreflective system: An assembly of retroreflective elements covered by a material with an enclosed air interface.

Retroreflective device: A complete system, ready for use, consisting of one or more retroreflective optical units.

## PHOTOMETRIC TERMS

Angle of Divergence: The angle subtended between observer's line of sight and direction of light incident on the reflecting surface at the center of the illuminated area.

Angle of Incidence: The angle between the direction of incident light at the center of the illuminated area and a line normal to the reflecting surface.

Specific Intensity: Candle power returned at a given angle of divergence or incidence by the reflecting surface for each footcandle of illumination at the reflecting surface and normal to the central incident ray on a unit reflector. Specific Intensity shall be calculated using the general formula as shown below:

$$S.I. = \frac{R \times d^2 \times K}{I}$$

where,

S.I. - Specific Intensity, in terms of candlepower per footcandle per unit reflector.

R - Reflected light intensity

I - Incident light intensity

d - Distance from test material to photocell, in feet

K - Transmission factor of color filter, if used
1.0 for crystal devices; 0.6 for amber devices.

Specific Brightness: Specific Intensity per unit area of the reflective material.

# APPENDIX A

# DETAILED TESTING PROCEDURES AND OBJECTIVES

## VISIBILITY ANALYSIS PROCEDURES

In order to study the relationship between the variable and environmental factors affecting them, a progressive series of five tests was used. The tests were: an initial sample and brochure review, a laboratory visibility test including photometric analysis, a full-scale static visibility test, a full-scale dynamic visibility test, and a nighttime motion picture analysis of a major installation. A description of each testing procedure including its objectives is detailed in the following paragraphs.

### Sample and Brochure Review

This test involved an informal, subjective analysis of all product brochures or materials submitted by the various manufacturers. The decision to request information or products from a particular company was made after a search through trade journals and correspondence with professional societies. If an unadvertised product seemed to have potential application to a center barrier installation, the manufacturer was requested to send a sample. Samples were rejected at this point if they failed to meet the following criteria:

1. A delineator must give light or be retroreflective.
2. All materials must be readily available for use and be practical to use.
3. Materials must have no potentially detrimental effects to motorists, vehicles or pedestrians.
4. Materials must have a minimum negative aesthetic intrusion on the barrier environment.

5. Mounting materials must not project more than 4 inches (10 cm.) from the surface of the safety barrier and must be a flexible springback or low profile design to minimize damage due to contact by passing vehicles.
6. Materials must be applicable to vertical and horizontal barrier surfaces.

If the sample met the above criteria, it was passed on to the next test.

Laboratory Visibility Test

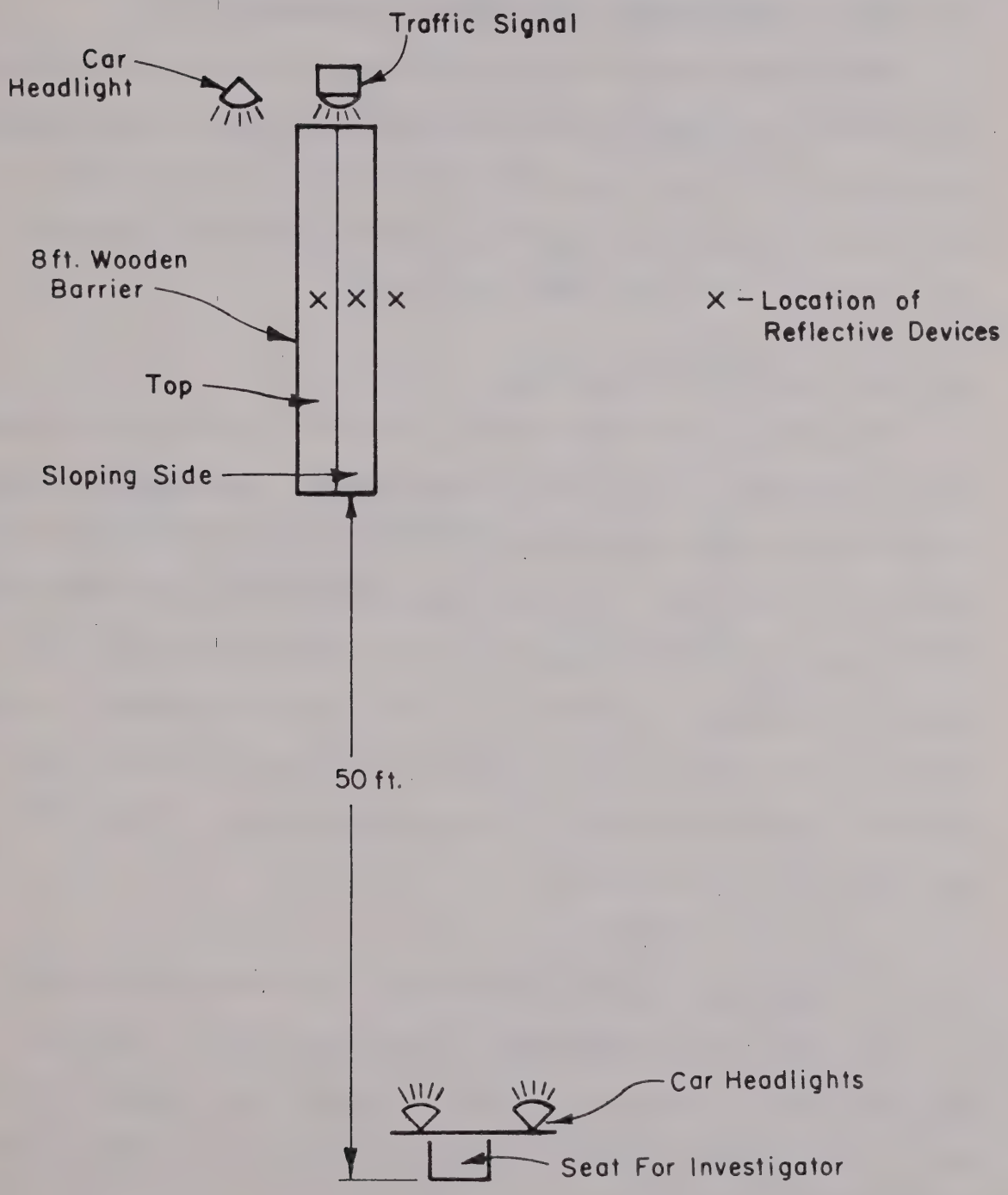
Since no devices that produced light were submitted, retroreflective devices alone were studied in this test, the objectives being:

1. To obtain a general understanding of the effects of water, headlight glare and traffic light glare on the reflectivity and visibility of the delineators.
2. To see if there were any obvious differences in the effects produced by positioning on the barrier and/or the pavement.
3. To obtain a comparative rating of the initial reflectivity of the devices.

This test was performed in the basement of the Research office by two project engineers. A full-sized wooden replica of the center barrier was constructed and used in this test. The devices were mounted at various heights on the barrier including at ground level (see Figure 6). Observers sat in a chair 50 feet away, as if in a car in the left lane of traffic while headlights illuminated the delineators. A set of headlights and a traffic signal were positioned in back of the delineators to simulate the effect of glare from these sources. Water was splashed on the delineators to see if this produced any detrimental effects on the reflectivity. The devices were also viewed at various incidence angles

Figure 6

SET-UP FOR LABORATORY VISIBILITY STUDY



in order to better understand the photometric results obtained from the NJDOT Materials Laboratory, using an ESNA reflex photometer.

In order to generate a comparative initial reflectivity rating, all delineators were viewed through a Luckiesh-Moss Visibility Meter and compared to engineering grade reflective sheeting.

Materials were rejected at this point only if they were determined to be inferior under any of the conditions outlined above. As an example, the reflectivity of open beaded reflective materials, mounted normal to the observer's vision, were radically reduced by the water splash and were, therefore, eliminated from further tests.

Full-Scale Static Visibility Tests

This test was performed in order to comparatively rate the brightness of the delineators in a nighttime field situation. The delineators were mounted on the wooden barrier used in the laboratory visibility test and rated by five engineers. The observations were performed at 0° and 30° angles of incidence and at 200 foot, 500 foot, and 1,000 foot distances (.5°, .2°, .1° angles of divergence, respectively) for each angle of incidence. (Refer to Figure 7). The objective of this test was to further reduce the total number of reflective devices still under consideration. Criteria used for rejection after this test were:

1. Relative visibility
2. Impractical mounting configuration for barrier installation.

After this test, six delineator devices and a type of reflective tape were chosen for the next evaluation, the full-scale dynamic visibility test. A description of these devices and the reasons for their selection can be found in Appendix C.

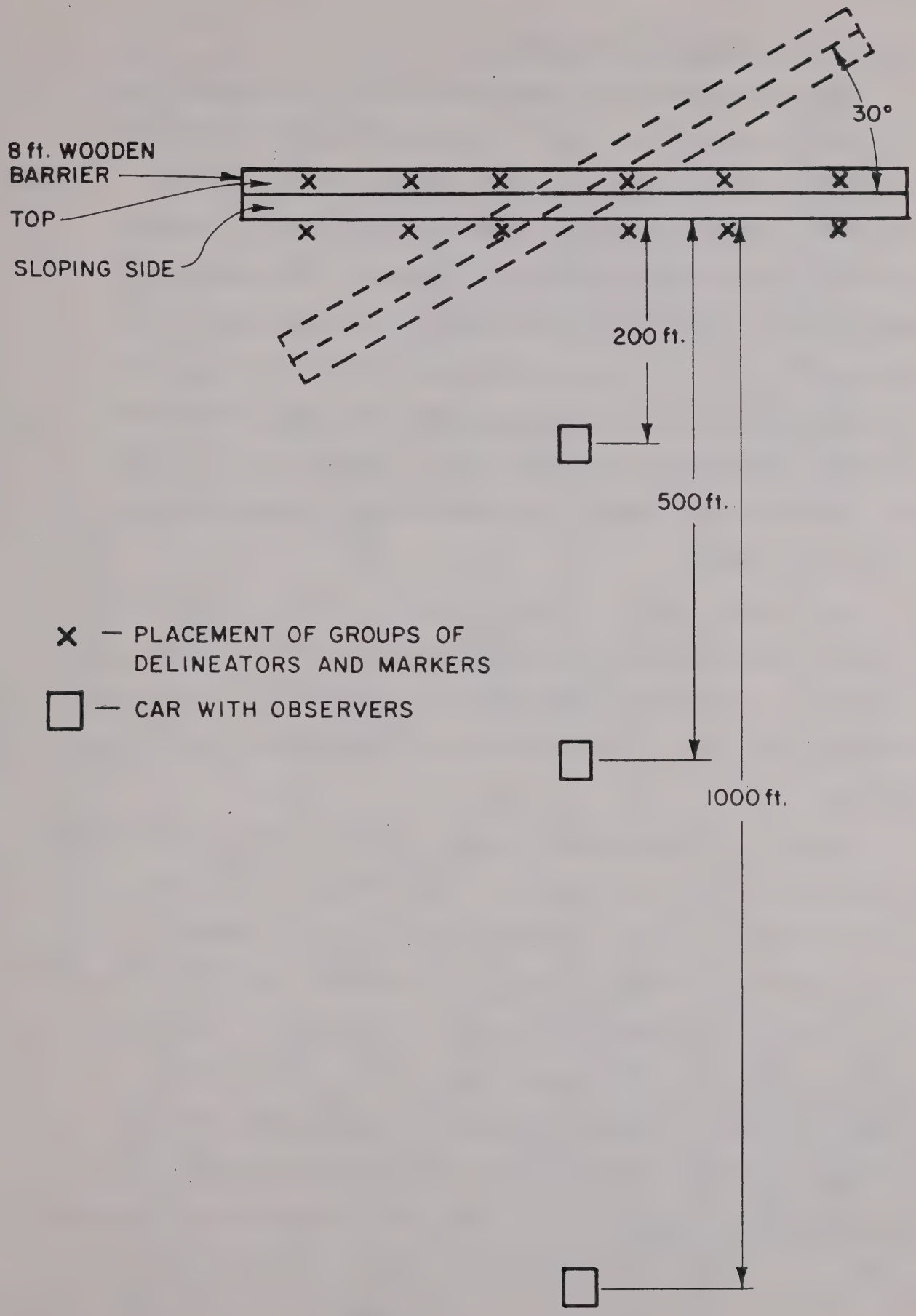



Figure 7

## SET-UP FOR STATIC VISIBILITY TEST

Full-Scale Dynamic Visibility Test

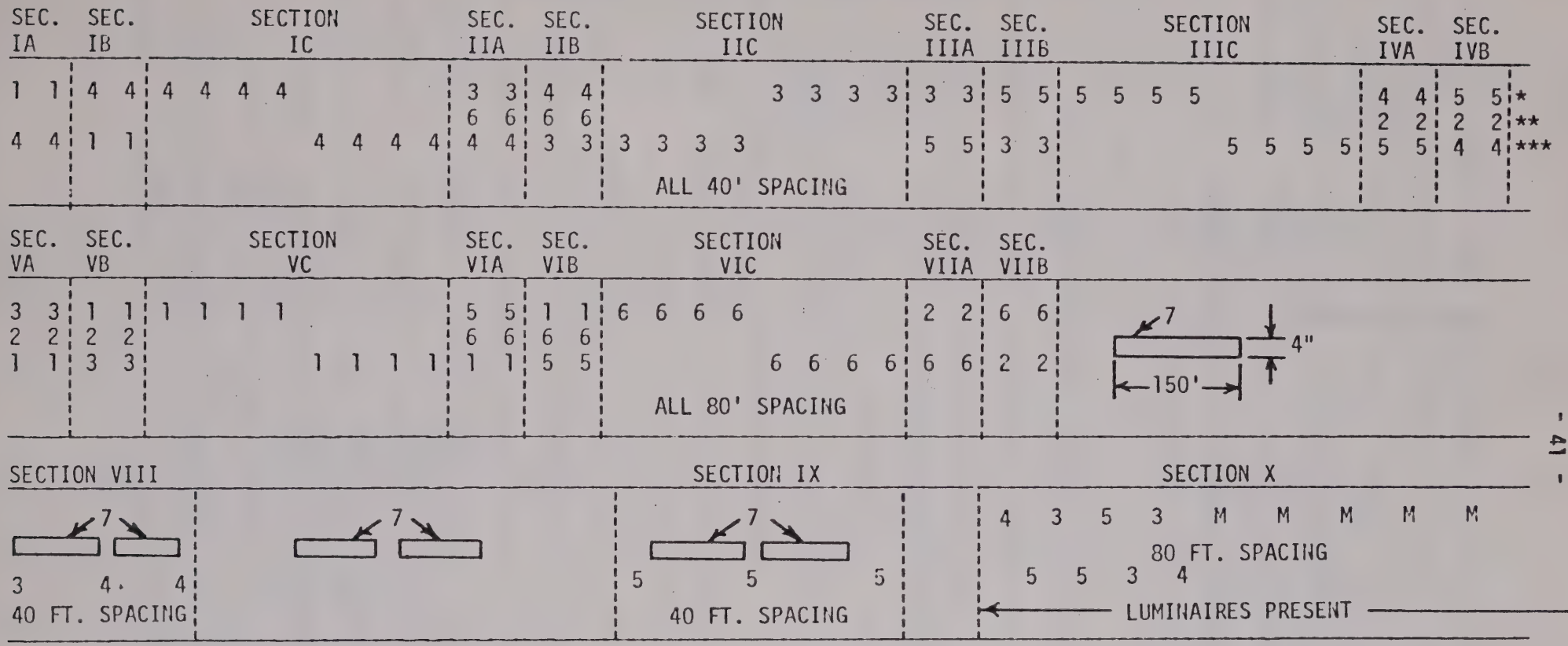
The three tests described above were performed to reduce the number of samples to be field evaluated by using the "new-clean" reflectivity ratings and the device's ability to be adapted for barrier use as rejection criteria. The dynamic visibility test, however, consisted of more complex objectives and testing procedures. The purposes of the test were twofold: first, to determine the optimum vertical positioning of the reflectors considering the effects of weathering from dirt accumulation and natural abrasion sand, damage from impacts, and glare; and second, to determine which of the six test devices and the reflective tape appeared the brightest after a period of exposure to the environment.

The location chosen for this test was the section of Route 1 near Trenton, between Whitehead Road and the merge of Route 1 and Route 1 Alternate. It was selected because of its close proximity to the NJDOT offices, the absence of luminaries and interchanges for a long stretch of road.

A total of 126 delineators and seven sections of the reflective tape were mounted on the northbound side of the barrier according to the plan in Figure 8. On the southbound side, 138 3M-BD-21 reflectors were mounted as indicated in Figure 9. In addition, after the reflectors in Section $\underline{X}$, black markers were mounted on the barrier. These markers were also mounted in the Whitehead Road vicinity with and without reflective tape. The purpose of installing these markers was to evaluate the effect of the appearance of delineators opposed to the contrast of black markers on the light colored barrier in an illuminated area.

FIGURE 8

LOCATION OF REFLECTORS ON RT. U.S.1, TRENTON
NORTHBOUND SIDE OF THE MEDIAN BARRIER


SEC. IA
SEC. IB
SECTION IC
SEC. IIA
SEC. IIB
SECTION IIC
SEC. IIIA
SEC. IIIB
SECTION IIIC
SEC. IVA
SEC. IVB
1 1 4 4 4 4 4 4 3 3 4 4 3 3 3 3 3 3 5 5 5 5 5 5 4 4 5 5 *
6 6 6 6 2 2 2 2 **
4 4 1 1 4 4 4 4 4 4 3 3 3 3 3 3 5 5 3 3 5 5 5 5 5 5 4 4 ***
ALL 40' SPACING
SEC. VA
SEC. VB
SECTION VC
SEC. VIA
SEC. VIB
SECTION VIC
SEC. VIIA
SEC. VIIB
3 3 1 1 1 1 1 1 5 5 1 1 6 6 6 6 2 2 6 6
2 2 2 2 6 6 6 6 6 6 2 2
1 1 3 3 1 1 1 1 1 1 5 5 6 6 6 6 6 6 2 2
ALL 80' SPACING
7
4"
150'
SECTION VIII
SECTION IX
SECTION X
7
7
7
3 4 4
40 FT. SPACING
5 5 5
40 FT. SPACING
4 3 5 3 M M M M M
80 FT. SPACING
5 5 3 4
LUMINAIRES PRESENT

REFLECTIVE DEVICES

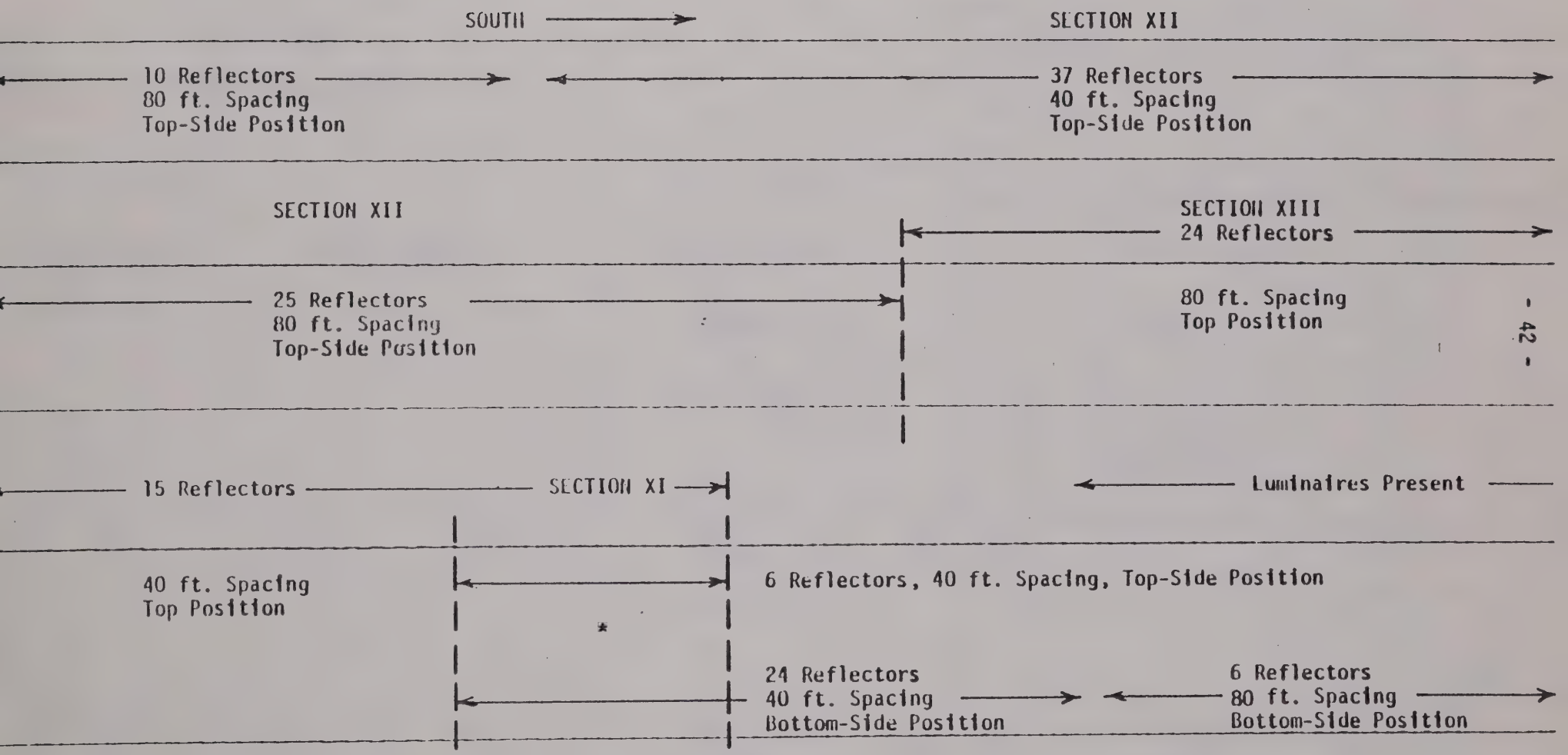
1 - Reflexite
2 - 3M BD-21
3 - Stimsonite 975
4 - Swareflex 3290
5 - Stimsonite 2400
6 - Stimsonite 960
7 - Scotchlane Tape
M - Black Markers

POSITIONS

*Top-Side - 5" from top of barrier
**Middle-Side - 9" from top of barrier
***Bottom-Side - 14" from top of barrier

FIGURE 9

LOCATION OF REFLECTORS ON RT. U.S. 1, TRENTON
SOUTHBOUND SIDE OF THE MEDIAN BARRIER




*Five sets were installed in Section XI,
each with top, top-side, and bottom-side reflectors.

Top Position - On top of the barrier
Top-Side Position - 5" from the top of the barrier
Bottom-Side Position - 14" from the top of the barrier

A team of observers rated the reflectors while in a vehicle moving in the left lane of traffic. The car travelled at 40 mph with the low headlight beams in operation. The team of observers consisted of engineers from the areas of Traffic Engineering, Maintenance, Quality Control and Research. Groups of three or four of the observers were driven through the test area and asked to evaluate the reflectors by filling out a questionnaire. The questionnaire instructions and forms are shown in Appendix C.

The rating was performed when the reflectors were new, after one winter of weathering, and after two winters of weathering. The identical questionnaire form and questions were used for the first two studies. However, due to damage to and loss of certain devices between the first and second winter, comparisons between reflective tape and delineators could not be repeated in the third study. In the third study, a question considering the adequacy of the delineators was added.

The dynamic ratings presented in Table 1 were determined in the following manner: each reflector was rated against the other reflectors individually. The percent of "reflector was chosen the most reflective" selection was determined by dividing the total number of most reflective selections given by the observers by the total number of comparisons with other reflectors. Responses of "equal" were not used in this analysis.

Insufficient barrier length prevented the six reflectors from being mounted in the fifteen "groups of two" configurations needed to individually compare the devices. However, care was taken to assign each reflector to the same number of "groups of two" and "groups of three."

In order to evaluate the effects of weathering photometrically, two reflectors of each type, one from the top-side position and one

from the bottom-side position, were removed from the northbound site of the barrier and tested in an ESNA reflexphotometer. The reflectors were tested in the same condition in which they were removed from the barrier and also after being cleaned. Tests were run at 0° and 30° incidence angles and .1°, .2°, and .5° divergence angles. In addition, three reflectors from Section XI on the southbound side of the test site were also removed and tested as stated above. The latter reflectors were 3M BD-21's, one each from the top, top-side and bottom side positions. After the photometric tests, all the reflectors were visually examined in order to note the effects of windblown particles. The purpose of these tests was to photometrically and visually document any differences in the effect of weathering on the various barrier height locations studied.

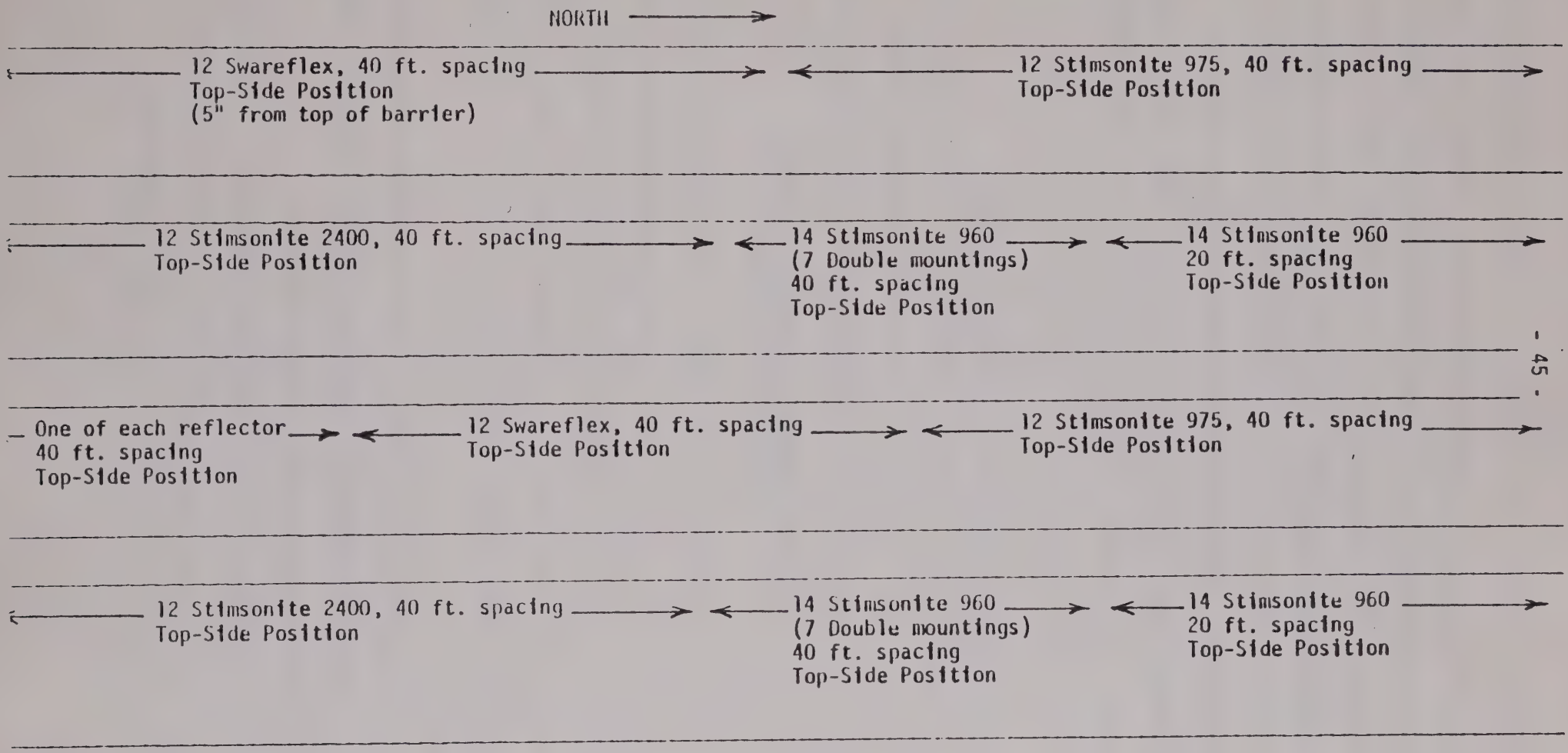
After the second dynamic study (after one winter of exposure), the four best devices were selected for the major installation on Route 1 in New Brunswick.

Motion Picture Analysis for the Major Installation

The purpose of this study was to evaluate the effects of headlight glare and wet, night conditions on a longer installation of each of four types of reflectors. One hundred and thirty-three reflectors were mounted on the barrier according to the plan in Figure 10. The location of the installation was Route 1 northbound, between Milltown Road and Ryders Lane in New Brunswick. This location was chosen to coincide with the snowplowable raised pavement markers which were installed at that location and because of the existence of a high volume of traffic which was needed to adequately analyze the effect of glare. The reflectors were all mounted at the top-side position (5 inches from the top of the barrier

FIGURE 10

LOCATION OF REFLECTORS ON RT. U.S. 1, NEW BRUNSWICK
NORTHBOUND SIDE OF THE MEDIAN BARRIER



After one year of exposure to the environment, color motion pictures were taken in both dry and wet night conditions. A Kodak XL 360 camera and Ektachrome ASA 160 Type G daylight film were used for this evaluation.

The driver and camera operator also made visual observations of the installation concerning the effect of glare and the number of reflectors which could be seen in advance of the vehicle. These observations were compared to similar observations taken from the film in order to gage how closely the picture compared, when projected on a screen, to the actual view of the road on the night the film was taken.

Material and Mounting Techniques Analysis Procedures

The mounting system consisted of three parts to be studied. First, the L-shaped bracket on which the reflector was fastened; second, the technique and materials used in attaching the reflector to the bracket and third, the technique and materials used in attaching the bracket to the barrier.

Samples submitted by manufacturers were considered along with the reflective materials in the Initial Sample and Brochure Review previously outlined. The materials accepted after this test were used in the dynamic visibility test and the major installation on Route 1, New Brunswick.

Reflector and mounting materials were monitored for the following qualities:

1. Durability of the materials, which included checking for bracket deformation, rusting and cracking; reflector damage, and rusting of attachment bolts and rivets.
2. Effectiveness of the attachment techniques which included checking for loose concrete studs; lifting or buckling of the adhesive pads; and missing reflectors and brackets.

# APPENDIX B

## DETAILED PRODUCT DESCRIPTIONS AND INITIAL MATERIAL TESTING RESULTS

Product Descriptions - Reflective Devices

Various manufacturers were asked to submit any products which fulfilled the following requirements:

1. Give light or reflect light from headlights, at night and in rain.
2. Be self-cleaning or easily cleaned.
3. Be durable.

The types of materials submitted for testing included standard acrylic cube corners, microscopic vinyl cube corners, encapsulated lens sheeting, silvered convex glass lenses, and exposed glass beads in a pigmented binder. All products were run through a progressive series of initial visibility tests to determine applicability for further use. A list of all products submitted and the reasons for their rejection or acceptance is in Appendix B. From the initial tests, which are detailed in the procedures section, six delineators and a type of reflective tape were chosen for the full scale dynamic tests. The product descriptions in the following paragraphs were taken from the interim report issued on this project (7). The delineator types and specific models chosen along with the basic reasoning why each one was selected is discussed. Cross sectional views of the devices can be seen in Figure 11.

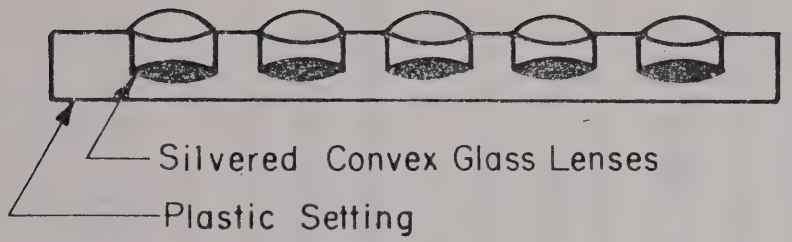
Standard Acrylic Cube Corners

Three models from this type of reflective device were selected for the dynamic tests. The are: Stimsonite 975, Stimsonite 960, and Stimsonite 2400, all manufactured by the Signal Products Division, Amerace Corporation.

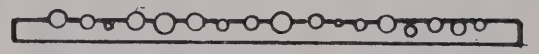
The Stimsonite 975 reflector was chosen because it had the highest

Figure 11

## Crossectional Views of Retro Reflectors

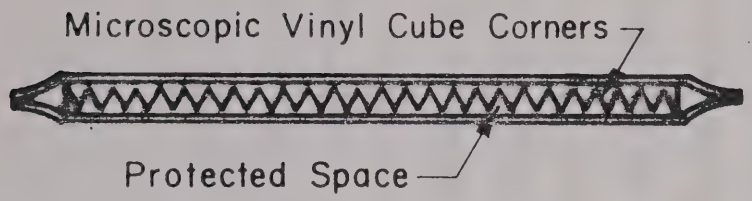



SWAREFLEX 3290

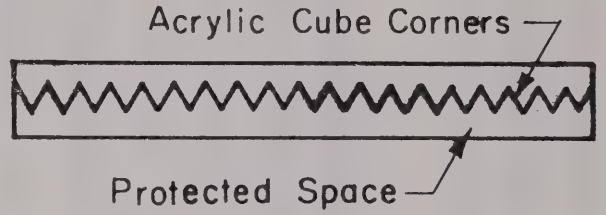


Spherical Glass Beads
In A Pigmented Binder

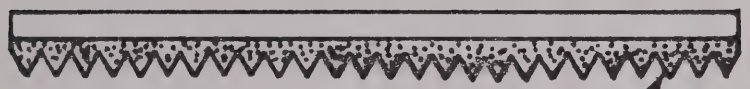
SCOTCHLANE TAPE




REFLEXITE

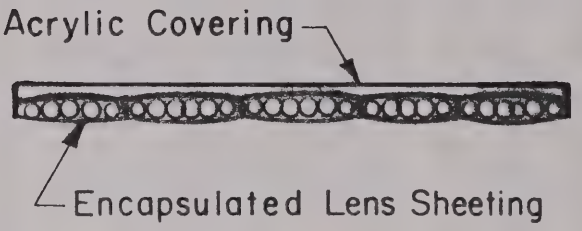



STIMSONITE 975 & 960



Silvered Acrylic Cube Corners
(No Protected Space)

STIMSONITE 2400




3M BD-21

specific brightness of any product tested. It should be noted that Stratolite reflectors, produced by the Miroflex Company has a specification equivalent to the Stimsonite 975. Because of the closeness of the Amerace Corporation (New Jersey) their reflector was thought easier to obtain and, therefore, selected for testing. The Miroflex delineator might provide similar results.

The Stimsonite 960 is an updated experimental version of the Stimsonite 88 model. Both are standard corner cube reflex devices. The Stimsonite 88 was developed as a raised pavement marker and the 960 model was designed specifically for a vertical barrier attachment. It has the same reflective area, is considerably lighter in weight, and has higher specific brightness values than the 88 model. Attachment of the reflector to the barrier is accomplished with a butyl adhesive backing and the device may be the most vandal proof of the chosen reflectors because of its shape. It is the only reflector with a low profile that was selected for further study. It was chosen because it was the brightest of the low profile devices tested and was provided with a potentially acceptable method of attachment.

The Stimsonite 2400 model contains a unique quality which is its wide angle characteristic. The orientation of the corner cubes in the standard corner cube reflectors is more normal to the reflective surface than in the wide angle model which is oriented at multiple angles to the surface. This apparently accounts for its relatively smaller decrease in specific brightness at a 30° incidence angle.

Microscopic Vinyl Cube Corners

The Rowland Development Corporation furnished the only vinyl

reflector in our study. The vinyl product, known as Reflexite Sheeting, is composed of microscopic vinyl cube corners. It was selected because of its relatively high brightness, flexibility and potential impact resistance.

Encapsulated Lens Sheeting

The 3M Company specifically developed a reflector (BD-21) for trial on median barriers. It employs encapsulated lens sheeting applied to a rubber mount which in turn is attached to a barrier with a butyl adhesive. It was selected for further study because it was the only type of encapsulated lens sheeting available and it is brighter and more durable than regular beaded sheeting.

Silvered Convex Glass Lenses

D. Swarovski and Company was one of three companies which supplied glass reflectors. Though another glass product had a higher specific brightness, it was unavailable in quantity and not adaptable to any available mounts. The Swareflex 3290 was thought to be advantageous and was selected for further study. Swareflex reflectors are provided with mounting holes and are not likely to leave shattered glass on the roadway, if damaged, as would another glass reflector considered.

Exposed Glass Beads in Pigmented Binder

Another 3M product, referred to as Scotchlane tape, was selected. Although it was not as reflective as other chosen devices, it was selected because of its uniquely different application. The striping is mounted on the side of the barrier as a long stripe designed to supply continuous barrier delineation. This high index bead striping should more than

adequately represent other exposed bead striping products, although there may be equivalent products of its type available from other manufacturers.

Product Descriptions - Mounting Devices

Manufacturers were asked to submit any materials which fulfilled the following requirements:

1. Applicable to a barrier mounting device;
2. Resistant to impact;
3. Of a flexible or springback design;
4. Easily installed.

The types of materials received and tested were butyl adhesives, epoxy adhesives, flexible plastic mounts, flexible plastic posts, rubber mounts, and studs shot into the concrete. A list of these products and the reasons for acceptance or rejection is in Appendix B.

Three types of mounting systems were used in the project. They were: metal mounts bolted to the median barrier, flexible mounts bolted to the barrier, and flexible mounts attached with a butyl adhesive.

The metal mounts were steel, painted for protection from weathering and supplied by the NJDOT sign shop. Metal mounts were used since, at the beginning of the major evaluations, a limited number of flexible mounts were available.

The flexible mounts were of two types. One was a custom 90° angle type, made of Ethylene Vinyl Acetate (EVA) and supplied by the Unipar Corporation. This material was chosen because of its resistance to permanent deformation from impact, bending failure, and weather. The other flexible mount was the scrap rubber mount which was part of the 3M BD-21 delineator. It was attached to the barrier with a butyl adhesive.

The concrete studs used were a #10, 1/4" Hilti Bolt, which were shot into the concrete using a Hilti DX-400B gun. The butyl adhesive was supplied by the Spatz Paint Company and required a minimum installation temperature of 60° F and a primer applied to the barrier to insure proper adhesion.

The smaller face of the mounts was applied flush with the barrier so that the larger face was in a vertical plane of reference. If the mount was bolted to the barrier, a 3/8" hole was drilled into the center of the smaller face through which the bolt was inserted. All mounts had a 3/8" hole drilled in the center of the larger face through which the delineators were bolted or riveted. When the butyl adhesive was used for application to the barrier, a piece equal in size to the smaller face was applied.

The mounts described above were used for the Stimsonite 975, Stimsonite 2400, Swareflex 3290 and Reflexite delineators. The Stimsonite 960 needed no mount but used a butyl adhesive and primer for attachment to the barrier. The 3M BD-21 was a complete reflector, mount and adhesive system which only needed to be applied with a primer. The 3M Scotchlane tape was an adhesive backed tape which also required a primer during mounting.

## INITIAL MATERIAL TESTING RESULTS

Product information and samples were requested from 42 companies. The companies are listed with their products and the letters A through E indicating at what point in the testing they were rejected or accepted as a prototype. Numbers 1 through 6 show the reasons for this acceptance or rejection.

A = Rejected - after a brochure or sample review

B = Rejected - after a laboratory visibility test

C = Rejected - after a full-scale static visibility test

D = Rejected - after a full-scale dynamic visibility test including a dirt accumulation variable

E = Accepted - product used as a prototype

1. Low relative visibility
2. Impractical mounting configuration for barrier installation
3. Not designed for application onto a mount
4. Difficult to apply on a vertical surface
5. Material developed but not able to get into proper configuration for testing
6. Conforms to project test and configuration requirements

| NAME OF COMPANY | PRODUCT | RESULT | REASONS FOR ACCEPTANCE OR REJECTION |
|---|---|---|---|
| Amerace Esna Corp. | a) Low profile reflector | E | 6 |
| | b) Flexible corner cube reflector | E | 6 |
| | c) Circular corner cube reflector | E | 6 |
| Several other products were submitted by the company and rejected for their inapplicable configuration | | | |
| American Decal & Manufacturing Co. | Engineering grade reflective sheeting | C | 1 |
| Cataphote Corp. | Reflective paint | B | 1 |
| Corning Glass Works | Glass lens & Multiple lens | C | 3 |
| Diamond Shamrock Chemical Co. | Epoxy adhesive | A | 4 |
| E.I. Dupont Da Nemours & Co. | Hytrel flexible plastic | A | 5 |
| Ferro Corp. | Reflective ceramic marker | C | 1 & 2 |
| Fasson Reflective Div. of Avery Products Corp. | Engineering grade reflective sheeting | C | 1 |
| Flexible Safety Zoning Co. (Div. of NAFISCO) | EVA flexible post with reflective paint[1] | C | 1 & 2 |
| General Electric Co. | Lighting | A | 5 |
| Good Year Tire & Rubber Co. | Rubber | A | 5 |
| Goodall Rubber Co. | Rubber | A | 5 |
| GTE Sylvania, Inc. | Lighting | A | 5 |

[1] EVA - Ethylene Vinyl Acetate

| NAME OF COMPANY | PRODUCT | RESULT | REASONS FOR ACCEPTANCE OR REJECTION |
|---|---|---|---|
| Harvey-Hubble Inc. (Lighting Division) | Lighting | A | 5 |
| Hawkins-Hawkins Co., Inc. | Lighting | A | 5 |
| Hilti Corp. | Concrete studs | E | 6 |
| Holophane Co. | Lighting | A | 5 |
| Intercoastal Corp. | Butyl adhesive | E | 6 |
| International Plastics, Inc. | Molded plastic | A | 2 |
| International Scanning Devices, Inc. | Electro-Luminescent material | A | 1 & 2 |
| Koppers Co., Inc. | Epoxy Adhesive | A | 4 |
| Lanco Industries Co. | Flexible delineator | A | 2 |
| MACTAC-Morgan Adhesive Co. | Engineering grade reflective sheeting | C | 1 |
| Mitsubishi International Corp. | Engineering grade reflective sheeting | C | 1 |
| Minnesota Mining & Manufacturing Co. | a) High intensity reflective sheeting | D | 1 |
| | b) Exposed glass beads in pigmented binder | B[1]<br>D[2] | 1<br>1 |
| Several other products were submitted by the company and rejected for their inapplicable configuration or low relative visibility. | | | |
| Miro-Flex Co., Inc.* | Circular corner cube reflector | E | 6 |
| Several other products were submitted by the company and rejected for their inapplicable configuration. | | | |
| Ovonic Displays Inc. | Electro-Luminescent material | A | 1 & 2 |

*Equivalent to Amerace Corporation
[1]Rejected for application in a plane normal to the drivers vision at this point
[2]Rejected for application in a plane tangent to the drivers vision at this point.

| NAME OF COMPANY | PRODUCT | RESULT | REASONS FOR ACCEPTANCE OR REJECTION |
|---|---|---|---|
| Potters Industries Inc. | Glass beads | A | 5 |
| Reflecting Road Studs Ltd. | Catseye Road studs | C | 2 |
| Rohm & Haas Co. | High intensity reflective sheeting | A | 5 |
| Reflexite Corp. | Vinyl micro corner cube | D | 1 |
| Royal Industries | Flexible post | A | 2 |
| Safe-T-Cone Div. of Radiator Speciality Co. | EVA flexible post | A | 2 |
| Spatz Paint Industries Inc. | Butyl adhesive | E | 6 |
| Snowfast | Synthetic rubber striping | A | 1 |
| Swarovski & Co. | Swareflex reflective glass lenses | E | 6 |
| Several other products were submitted by the company and rejected for low relative visibility. | | | |
| Permaline Co. | Thermo plastic striping | A | 4 |
| UNIPAR Inc. | Flexible mount EVA | E | 6 |
| Several other products were submitted by the company and rejected for their inapplicable configuration. | | | |
| Westinghouse Electric Corp. | Lighting | A | 5 |

# APPENDIX C

## QUESTIONNAIRE INSTRUCTIONS AND FORM

## QUESTIONNAIRE INSTRUCTIONS FOR DYNAMIC VISIBILITY TEST

Use low beams while driving in the left lane at 40 mph. Use car flashers and a roof-mounted flasher facing to the rear.

Questions 1A thru 7A - The first time while traveling north on Route 1 from Whitehead Road, consider the "A" groups. The "A" groups are the first two sets of vertically aligned reflectors at each location, each set containing either two or three reflectors.

Rate both top reflectors vs. both bottom ones (and both middle reflectors, where appropriate). Do not rate the first top against the first bottom and then the second top against the second bottom.

Mark down which reflectors (top, middle, bottom) appear to be the brightest to you. If you feel there is no difference between the top, and/or bottom, and/or middle, mark down those you think are equally the brightest, i.e., TB, MB, TM, TMB. Do not use equal or no preference.

Question 8 - In Section X, compare the eight reflectors located at two levels with the string of black markers, and the barrier itself. Select which of the three situations you would prefer to have in an illuminated area.

Question 9 - On the return trip, while traveling south on Route 1, look for the area where there are three reflectors aligned vertically, one on top of the barrier and two along the side. Rate these as the "A" groups were rated.

N.B. The top in this grouping is on top of the barrier while in the above "A" and "B" groups the top is the highest mounted side reflector.

Question 1B thru 7B - Going north again, rate the "B" groups at each of the locations in the same manner as the "A" groups. The "B" groups are the second two sets of vertically aligned reflectors at each location.

Question 10 - Returning south, in the vicinity of Whitehead Road, compare three situations and select which you would prefer to have on the barrier in an illuminated area. The groups are: first, tape with black markers; second, black markers alone; and third, the barrier itself.

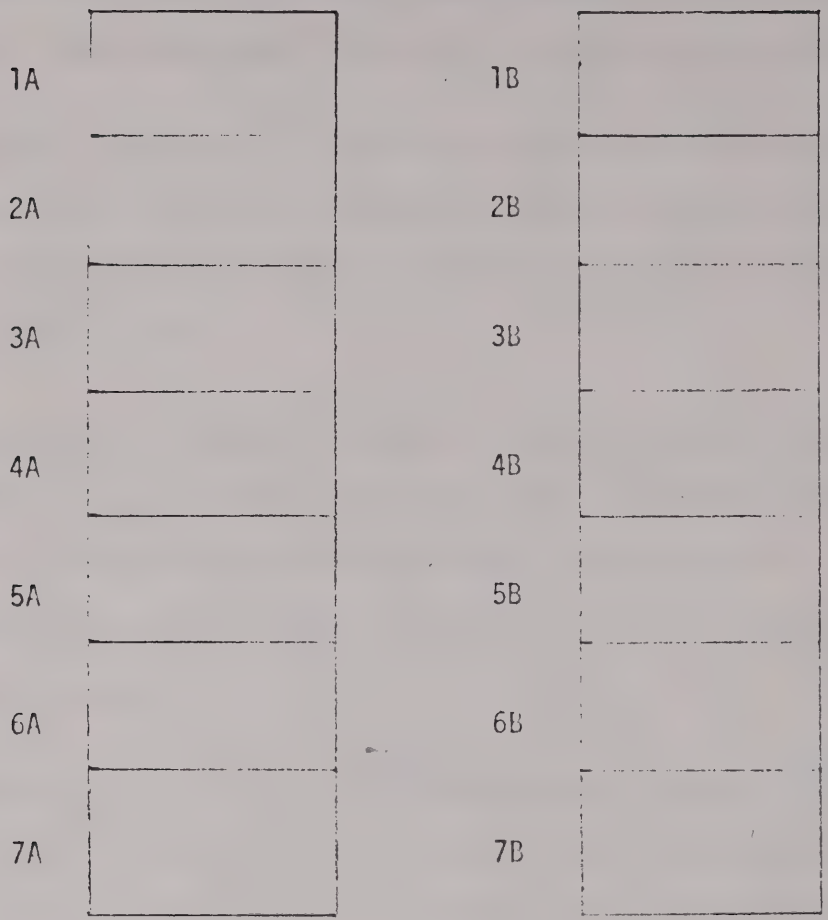
Question 11 - Traveling northbound again, consider the reflectors in Sections I-C, II-C, III-C, V-C and VI-C. These reflectors consist of four at the top position followed by four at the bottom position. Choose overall, not by the individual areas, which height you prefer the reflectors at.

N.B. The group of reflectors in Section II-C run bottom-top as opposed to those in I-C, III-C, V-C and VI-C which are mounted top-bottom.

Questions 12 and 13 - Traveling northbound, consider sections VIII and IX. Choose whether the reflectors or the tape appear to be the brightest. Section VIII corresponds to Question 12 and Section IX with Question 13.

Answer Questions 14 and 15 on the second page of the questionnaire to the best of your ability. These questions concern the effect of opposing headlight glare on the visibility of the reflectors and tape.

CENTER BARRIER VISIBILITY STUDY
FIELD DATA QUESTIONNAIRE




Name_____

Date_____

Car Position_____

In answering Questions 8-13, please circle only one choice.

8. Reflectors
   Black Markers
   Barrier

9. Top
   Middle
   Bottom

10. Tape and Black Markers
    Black Markers
    Barrier

11. Reflectors at Height 1 (Top)
    Reflectors at Height 2 (Bottom)

12. Tape
    Reflectors

13. Tape
    Reflectors

14. Did opposing headlight glare affect your vision of the reflectors? Did opposing headlight glare differently affect reflectors mounted at different heights? Please briefly describe how.

15. Did opposing headlight glare affect your vision of the tape? If so, please briefly describe how.

Question 16 - Do the following types of reflectors reflect an adequate (A) or inadequate (I) amount of light to be effective delineators?

a. All the reflectors on Southbound U.S. 1

. Top-Side (Section XII)

Top (Section XIII)

b. Reflectors in Section II-C

Bottom-Side

Top-Side

c. Reflectors in Section V-C

Top-Side

Bottom-Side

d. Reflectors in Section VI-C

Top-Side

Bottom-Side

# APPENDIX D

# COST ESTIMATE INFORMATION

For the purpose of estimating the cost of installation, a hypothetical operation is described for a stretch of 2.0 miles of curved sections or 3.5 miles of tangent sections of New Jersey highways.

A safety set up involving one pickup truck, one driver and three laborers is needed for a full day's operation. Two laborers place, move and remove the signs and cones for a half hour in the morning, afternoon, and evening. One laborer is a flagman during these operations. The left lane is closed to traffic for about 1 - 1.75 miles which is the expected length of the installation which can be completed by lunch break. After lunch, two laborers move the signs and cones 1- 1.75 miles downstream, again utilizing a flagman.

When the safety set up is complete, the three laborers are engaged in the installation of the delineators. One laborer shoots the concrete studs into the top of the concrete barrier at the proper spacing. The second laborer cleans the immediate area surrounding the bolt with a wire brush and applies the primer. When the primer is dry, the third laborer mounts the delineator assembly and bolts it to the Hilti bolt while applying an even pressure on the butyl pad. The two additional laborers included in the labor cost estimates are used to assemble the delineator units.

Installation Costs

| | | |
|---|---|---|
| Equipment Cost for Safety Operations | | $20 |
| 3/4 ton pickup truck @ $2/hr. | $16 | |
| Depreciation on cones | $ 4 | |
| Equipment Cost to Install Concrete Studs | | $16 |
| One DX400E gun @ $2/hr. | $16 | |

| | | |
|---|---|---|
| Labor Cost for Safety and Installation | | $283 |
| 1 Assistant Foreman @ $5.41/hr | $ 43.28 | |
| 4 Maintenance Men I @ $3.84/hr. | $121.60 | |
| 1 Flagman @ $3.84/hr. | $ 30.40 | |
| Overhead charges (45%) | $ 87.90 | |

Estimation of Delineators Installed Per Day

| | | |
|---|---|---|
| Time available for installation | 5 hrs. | |
| Travel time | 1 hr. | |
| Safety operations | 1.5 hrs. | |
| Two coffee breaks | .5 hr. | 8 hrs. |
| Average time to walk one mile | 20 min. | |
| 25% Fatigue factor | 5 min. | 25 mins. |
| Time to walk 40 ft., for curve installation | 15 sec. | |
| Time to walk 80 ft., for tangent installation | 25 sec. | |
| Time to load Hilti gun | 20 sec. | |
| Mark the barrier and shoot the gun | 20 sec. | |
| 25% fatigue factor for gun operation | 10 sec. | |
| Time for 1 bolt installation, curve | 65 sec. | |
| Time for 1 bolt installation, tangent | 75 sec. | |

The stud installation is the limiting factor since the primer application and delineator mounting take less time.

| | |
|---|---|
| Number of installations per hour - curve | 55 |
| Number of installations per hour - tangent | 48 |
| Total installations in 5 hours - curves | 275 |
| Total installations in 5 hours - tangent | 240 |
| Miles of installation per day - curve | 2 miles |
| Miles of installation per day - tangent | 3.5 miles |

| | | |
|---|---|---|
| Estimated Cost of One Delineator Assembly | | $1.79 |
| Primer | $0.05 | |
| 1 EVA bracket and butyl adhesive pad | $0.65 | |
| 2 reflectors - Stimsonite 975 (Miroflex 75) | $0.54 | |
| 1 W6-38-22 S12 Hilti bolt | $0.29 | |
| 1 booster shot for Hilti bolt | $0.10 | |
| 1 slotted panhead S.S. bolt | $0.04 | |
| 2 S.S. nuts | $0.08 | |
| 1 S.S. washer | $0.04 | |
| Estimated Cost of Delineator Assemblies per Day | | |
| Curves - 275 x $1.79 | $492 | |
| Tangent - 240 x $1.79 | $430 | |
| Cost per foot on curved sections | | |
| Total cost to install 275 delineators over 2 miles of curved highway (one day's work) | $811 | |
| Cost per mile | $406 | |
| Cost per ft. to delineate the barrier | $0.08* | |
| Cost per foot on tangent sections | | |
| Total cost to install 240 delineators over 3.5 miles of tangent section (one day's work) | $749 | |
| Cost per mile | $214 | |
| Cost per ft. to delineate the barrier | $0.04* | |
| Barrier cost per foot | $25 - $38** | |

*Multiplying these figures by a factor of 2 does not seem unreasonable since the labor costs and rates used are for an optimum situation. Any delay will cause the cost per foot to increase. As already noted in this report, the concrete stud does not always properly penetrate the barrier which necessitates the installation of another stud.

**The barrier cost per foot was supplied by the Bureau of Construction Practices, New Jersey Department of Transportation.

# APPENDIX E

# CORRELATION OF LABORATORY AND FIELD TESTING RESULTS

Statistical analyses were performed to see if a significant correlation existed between laboratory photometric results and the static and dynamic field results. Specifically it was desired to see whether the rankings of delineators and pavement markers generated in the static and dynamic tests could have been obtained using only photometric values. Spearman's Formula for rank correlation was used in the analysis. The significance of the correlations was determined using a one-tailed test at the 95 percent level.

Prediction of static field performance of retroreflective devices from laboratory test results appears good for delineators at 0° incidence angle but not at 30° incidence angle (Table 6). Pavement markers yielded mixed results with significant correlations for white markers but not for yellow. However, in all cases studied, the rank correlation decreased as the divergence angle increased. Since larger divergence angles correspond to smaller distances between observer and reflector, Weber's Law may be responsible for this phenomena. This law states that "a stimulus must be increased by a constant fraction of its value to be just noticeably different." (8) At larger divergence angles (shorter distances) retroreflectors will appear brighter to the observer. Accordingly, a larger difference between devices is needed in order for the observer to discriminate between them. Photometric results, on the other hand, are not governed by Weber's Law, therefore, the significant correlation between these groups of rankings could decrease.

Comparison of dynamic field results with laboratory values supports this view (Table 7). Unweathered devices yielded a non-significant correlation while weathered devices gave significant correlations at both the top-side and bottom-side positions.

TABLE 6

CORRELATION OF LABORATORY PHOTOMETRIC AND STATIC VISIBILITY RANKING

| DY GROUP | 0°/.1°* LR | 0°/.1°* FR | 0°/.2° LR | 0°/.2° FR | 0°/.5° LR | 0°/.5° FR | 30°/.1° LR | 30°/.1° FR | 30°/.2° LR | 30°/.2° FR | 30°/.5° LR | 30°/.5° FR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DY-1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 |
| DY-2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 2 | 5 |
| DY-3 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 3 |
| DY-4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 3 | 3 | 1 | 3 | 1 |
| DY-5 | 3 | 3 | 2 | 2 | 2 | 2 | 2 | 2 | 1 | 3 | 1 | 2 |
| | $r_{rank}$=1.0 (S) | | $r_{rank}$=1.0 (S) | | $r_{rank}$=1.0 (S) | | $r_{rank}$=0.9 (S) | | $r_{rank}$=0.6 (NS) | | $r_{rank}$=0.1 (NS) | |
| DWY GROUP | LR | FR | LR | FR | LR | FR | LR | FR | LR | FR | LR | FR |
| DWY-1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 2 | 1 | 4.5 |
| DWY-2 | 4 | 4 | 5 | 5 | 6 | 4 | 4 | 4 | 4 | 3 | 2 | 2 |
| DWY-3 | 6 | 6 | 6 | 6 | 5 | 6 | 6 | 5 | 6 | 4.5 | 6 | 1 |
| DWY-4 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4.5 | 4 | 6 |
| DWY-5 | 5 | 5 | 4 | 4 | 4 | 5 | 5 | 6 | 5 | 6 | 5 | 3 |
| DWY-6 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 1 | 2 | 1 | 3 | 4.5 |
| | $r_{rank}$=1.0 (S) | | $r_{rank}$=1.0 (S) | | $r_{rank}$=.829 (S) | | $r_{rank}$=.886 (S) | | $r_{rank}$=.757 (NS) | | $r_{rank}$=.357 (NS) | |
| MY GROUP | LR | FR | LR | FR | LR | FR | | | | | | |
| MY-1 | 5 | 4 | 4 | 5 | 4 | 5 | | | | | | |
| MY-2 | 4 | 4 | 3 | 4 | 3 | 2 | | | | | | |
| MY-3 | 3 | 4 | 5 | 3 | 5 | 3 | | | | | | |
| MY-4 | 1 | 1 | 1 | 1 | 1 | 1 | | | | | | |
| MY-5 | 2 | 2 | 2 | 2 | 2 | 4 | | | | | | |
| | $r_{rank}$=0.9 (S) | | $r_{rank}$=0.7 (NS) | | $r_{rank}$=0.5 (NS) | | | | | | | |
| MW GROUP | LR | FR | LR | FR | LR | FR | | | | | | |
| MW-1 | 7 | 6.5 | 7 | 7 | 6 | 6.5 | | | | | | |
| MW-2 | 4.5 | 6.5 | 4 | 6 | 4 | 5 | | | | | | |
| MW-3 | 4.5 | 4 | 5 | 4.5 | 5 | 6.5 | | | | | | |
| MW-4 | 1 | 1 | 1 | 1 | 1 | 1 | | | | | | |
| MW-5 | 6 | 5 | 6 | 4.5 | 7 | 4 | | | | | | |
| MW-6 | 2 | 3 | 2 | 3 | 2 | 3 | | | | | | |
| MW-7 | 3 | 2 | 3 | 2 | 3 | 2 | | | | | | |
| | $r_{rank}$=.866 (S) | | $r_{rank}$=.848 (S) | | $r_{rank}$=.741 (S) | | | | | | | |

D - Post delineator

M - Pavement marker

W - White (crystal)

Y - Yellow (or amber)

Spearman's Rank Correlation

$$r_{rank} = \frac{1 - 6D^2}{N(N^2 - 1)}$$

D = Differences between ranks of corresponding pairs

N = Number of pairs of values

(S) - Significant
(NS) - Not Significant

LR - Lab Rank
FR - Field Rank

* 0°/.1° = incidence angle/divergence angle

Tests of rank correlation significance are all a one-tailed test at the 95 percent confidence level.

TABLE 7

CORRELATION OF LABORATORY PHOTOMETRIC
AND 3rd DYNAMIC FIELD STUDY RANKINGS

| | Unweathered Delineators | | Weathered Delineators | | | |
|---|---|---|---|---|---|---|
| | | | Top-Side Position | | Bottom-Side Position | |
| | Lab Rank | Field Rank | Lab Rank | Field Rank | Lab Rank | Field Rank |
| | 0°/.5°* | 0°/.5° | 0°/.5° | 0°/.5° | 0°/.5° | 0°/.5° |
| Reflexite | 2 | 2 | 6 | 6 | 6 | 6 |
| 3M BD-21 | 4 | 6 | 5 | 5 | 4 | 5 |
| Stimsonite 975 | 1 | 1 | 2 | 2 | 4 | 2 |
| Swareflex 3290 | 6 | 3 | 1 | 1 | 1 | 1 |
| Stimsonite 2400 | 3 | 4 | 3 | 3 | 2 | 3 |
| Stimsonite 960 | 5 | 5 | 4 | 4 | 4 | 4 |

$r_{rank} = 0.600$
Not significant at the 95% confidence level using a one tailed test.

$r_{rank} = 1.000$
Significant at the 95% confidence level using a one tailed test.

$r_{rank} = 0.829$

Spearman's Rank Correlation:

$$r_{rank} = \frac{1 - 6\,D^2}{N\,(N^2-1)}$$

D = difference between ranks of corresponding pairs

N = numbers of pairs of values

* 0°/.5° = incidence angle/divergence angle

Since the unweathered devices were brighter than the weathered devices, Weber's Law may again account for the difference in correlation.

Whether weathered field performance could be predicted from laboratory photometric tests was also investigated. Table 8 lists the new photometric rankings and the final field rankings of the six delineators used in the dynamic field studies. A very poor correlation exists between the two rankings which is not surprising considering the varied reflective elements and surface materials used. The important finding is that initial laboratory tests cannot compensate for the different rates at which the delineator surfaces are affected by dirt and windblown particles.

TABLE 8

CORRELATION OF NEW PHOTOMETRIC AND
FINAL FIELD RANKINGS

| | New Photometric Rank (Unweathered) | Final Field Rank (3rd Dynamic Study) |
|---|---|---|
| Reflexite | 2 | 6 |
| 3M BD-21 | 4 | 5 |
| Stimsonite 975 | 1 | 2 |
| Swareflex 3290 | 6 | 1 |
| Stimsonite 2400 | 3 | 3 |
| Stimsonite 960 | 5 | 4 |

$r_{rank} = -0.257$

Not significant at the 95% confidence level using a one tailed test.

## LIST OF REFERENCES

1. Alexander, G. and Lunenfeld, H., Positive Guidance in Traffic Control, U.S. Department of Transportation, Federal Highway Administration, April, 1975.

2. Van Lear, G.A., "Reflectors Used in Highway Signs and Warning Signals, Parts I, II, III" Journal of the Optical Society of America 30, October, 1940, pp. 462-487.

3. Yu, Jason C., "Median Visibility Improvements: Needs, Methods and Trends," Highway Research Record 366, p. 93.

4. Morris, R., Mounce, Button, J., and Walton, N., Driver Visual Performance During Rainfall, Texas Transportation Institute, January, 1977.

5. Cook, Kenneth, Reflector Analysis, Century Research Group, Arlington, Virginia, August, 1969, pp. 163-164.

6. Federal Test Method Std., 370, "Instrumental Photometric Measurements of Retroreflective Materials and Retroreflector Devices."

7. Gertler, J., Roberts, A., Reilly, E., and Hollinger, R., Center Barrier Visibility Study Interim Report, unpublished report, New Jersey Department of Transportation, July, 1975.

8. Woodworth, R.S. and Schlosberg, H., Experimental Psychology, Henry Holt and Company, New York, 1958, p. 194.

## ACKNOWLEDGEMENTS

The author wishes to acknowledge the assistance provided by the following individuals and groups in completing this project:

Arthur Roberts for his guidance and technical support in all phases of the project, including his critique and editing of this report.

R. L. Hollinger and E. F. Reilly for their project direction and administrative assistance.

Jeffrey Gertler and M. V. Jagannath for their work in coordinating much of the field work.

The Bureau of Maintenance for the safety setups supplied by the Lawrence and College Farm Yards.

The members of the Delineation Committee for their generous donation of time, technical evaluation and ideas.

The various manufacturers who supplied the reflective and mounting materials used in the project.

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